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Technological developments affecting naval warfare requirements and the demands of scientific programs have directed emphasis on structures in deep ocean areas. The overall objective of this manual is to provide information on environments, systems, and techniques relative to construction in such areas. This chapter contains data on buoys and deep-water anchorage systems, for the restraint of structures on the surface, on the bottom, and at intermediate levels. New concepts are considered, as well as extended uses of conventional shallow-water anchorages. Types and uses and the fabrication, installation, protection, and maintenance of promising systems are discussed from the standpoint of deep ocean applications.

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STRUCTURES IN DEEP OCEAN

ENGINEERING MANUAL FOR UNDERWATER CONSTRUCTION

CHAPTER 7. BUOYS AND ANCHORAGE SYSTEMS

October 1965

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

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STRUCTURES IN DEEP OCEAN

ENGINEERING MANUAL FOR UNDERWATER CONSTRUCTION

CHAPTER 7. BUOYS AND ANCHORAGE SYSTEMS

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by

J. E. Smith

ABSTRACT

Technological developments affecting naval warfare requirements and the demands of scientific programs have directed emphasis on structures in deep ocean areas. The overall objective of this manual is to provide information on environments, systems, and techniques relative to construction in such areas. This chapter contains data on deep-water anchorage systems, for the restraint of structures on the surface, on the bottom, and at intermediate levels.

The present state-of-the-art for deep ocean anchorages does not permit fulfillment of all requirements. However, numerous significant achievements illustrate present capabilities, and reference to established practices for conventional shallow-water anchorage systems offers useful guidelines. Here, the purpose is to present deep-ocean anchorage capability in this perspective.

Since much early deep-water anchoring experience was obtained with buoys, and since these often form important elements in complex anchorage systems for other structures, the first part of the chapter is devoted to buoys and their accessories. Types, uses, fabrication, and maintenance are discussed, primarily from the standpoint of deep ocean application.

Design of deep ocean anchorages begins with basic considerations, such as means of securing to the bottom and forces acting on a moor. Standard drag-type anchors appear to offer the greatest potential in the near future for securing large complex structures to the ocean floor, though such anchors have small resistance to uplift forces. Novel anchors which are explosively embedded or drilled into the bottom are being developed; these possess uplift- as well as lateral-resistance capabilities. Calculation of the mooring leg configurations in deep water has been accomplished for a number of installations by using the basic design approach in which the catenary is broken into segments.

Design of anchorage systems is also influenced by miscellaneous considerations: chemical and physical conditions, marine life, operating limit of the seas, legal requirements, and interference with surface elements of anchorages from outsiders.

The hardware for deep ocean anchorages may be grouped into the three major categories of bottom implements, connecting apparatus, and accessories. Much of this hardware is in the experimental stage, and standard items frequently serve in unorthodox ways. Bottom implements being used include conventional as well as explosive anchors, pilings, footings, and the like. Rope of both metallic and synthetic construction is the prime means of connection in anchorage systems, each type having advantages in certain applications. The use of chain is generally restricted to the upper and lower extremities of the mooring leg. Among accessories, separation devices, bottom detectors, and special connectors are receiving increased development effort.

Although deep-ocean anchorage experience is limited, a number of significant anchorage systems have been achieved. Buoy systems are the most common. Single- and two-buoy taut-line systems, slack-line, and multileg systems comprise the major divisions of accomplished buoy anchorages. In general, they have used deadweights or small standard anchors as bottom implements and synthetic rope for the connecting apparatus. One especially successful slack-line system utilized synthetic rope of two different densities, one buoyant and the other nonbuoyant, creating "S"-shaped leg configurations with a combination of desirable characteristics.

Anchorages for major structures have included single-leg flexible, multileg flexible, and bottom-rest systems. The flexible-leg systems have employed standard drag-type anchors and wire rope for the connecting apparatus. One bottom-rest system has been constructed in a 200-foot depth more than 50 miles offshore, thus qualifying as a deep-ocean structure. It rests on drilled-in piles and structural tube legs.

Dynamic anchoring is a method of maintaining a floating structure on station and oriented in one direction by means of power units. These may be an integral part of the structure or positioned on separate flotation units but attached with cables or lines to the main structure. Power systems range from conventional ships' propellers to the hydraulic jet type. Sensing devices are used to relate to the fixed datum point. These include sonar, radar, and the taut-line wire system, in which a taut-wire line is anchored to the ocean bottom with accurate detection of wire line angularity attained through tiltmeters, transmitting power impulses through a computer.

Protection of anchorages in deep water presents serious problems not fully solved. Coatings of vinyl paints and epoxy resins have been found efficient in protecting the upper portions of systems against the marine environment. The use of cathodic protection systems can be extended to the lower levels. At least one major deep-ocean installation has had cathodic protection incorporated into its construction.

Operations and service in installing deep-ocean anchorage systems and recovering components are complex. Primary items of equipment include winches, tensiometers, and underwater gear and cameras. Important procedural steps in placement of a moor are the assembly and lowering of components to the ocean floor. Lowering has been accomplished both by free fall and rigid control. Recovery capability is desirable especially in the case of contemplated long-term anchorage systems, for replacement and recovery purposes. Recovery operations have utilized actuating coded acoustic command separation devices and grappling.

Adequate means of identification of deep ocean buoys, anchored or free floating, is a design problem for each installation. Rules for the marking and identification of fixed oceanographic stations have been formulated by the Inter-Governmental Oceanographic Commission and recommended to member nations. Locating and tracking buoys has been accomplished with the use of visual aids, radar, sound signals, and radio.

New concepts and developments in deep-water anchorage systems include an unmanned, 40-foot-diameter, disk-shaped oceanographic data station, a self-reeling submerged float, and a constant-relationship hoist for safely lowering heavy loads to the ocean floor.

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PART 1
BUOYS

1-1. GENERAL.

This part deals with buoys, their types and purposes, fabrication and maintenance. Accessories are discussed in detail.

Buoys (and buoy anchorage systems) have been used for centuries, but chiefly in waters less than 500 feet deep. Now buoy systems are being designed for use at depths as great as 30, 000 feet. Such application presents new problems. Solutions to many of these are still pending, with investigative work continuing.

1-2. DEFINITIONS AND USES.

In general, a buoy can be defined as an anchored or free-floating buoyant object, submerged or nonsubmerged, that is intended to warn of hazards or installations, to impart other information, or to serve as a component of an installation. Buoys may consist of wood, metal or synthetic material such as fiber glass, and may vary in size and nature from a log to a large, compartmented steel floating structure hundreds of feet long. It is the purpose to which the floating object is put that qualifies it as a buoy. In deep ocean work, uses of buoys may vary from simple surface markers to stations that telemeter information from 3, 000 miles at sea.

1-3. DESIGNS.

Buoys should be designed to respond favorably to the environment in which they function. In general, buoys should be as small and light as possible and still capable of performing their mission.

1-4. Surface Use.

Disk-, cone-, skiff-, and spar-shaped buoys (Figures 1-1 and 1-2) are used almost exclusively near the surface in deep ocean applications because their contours enable them to respond favorably to variations in surface conditions; the spar-shaped buoy has the further asset of less tendency toward vertical excursion than the others.

Each of the configurations named may take additional shapes which are variations of a primary form. Thus, the disk can appear as a toroid (a circular construction with a hole in the center, like a doughnut), or as a solid disk with evenly rounded perimeter, or as a solid disk with a many-sided perimeter. Similarly, cone buoys, though usually in the shape of an inverted cone, may vary in degree of inversion and truncation. A skiff buoy may be a boat or catamaran, and a spar buoy may vary considerably in length-to-diameter ratio while retaining its essential principle (Figure 1-2).

Each of the above configurations has characteristics that are of advantage or disadvantage depending on the requirements involved in any particular situation.

1-5. Disk Buoys. Disk buoys are relatively easy to construct, and moderate in cost. An ordinary disk buoy 8 feet in diameter, constructed of fiber glass, costs approximately $4, 000. Such buoys are practical for use where tow-under action is desired or permissible and where surface-following action is not detrimental. Disks have low capsize moments, especially if a long, submerged bridle is attached to serve as a stabilizing pendulum.

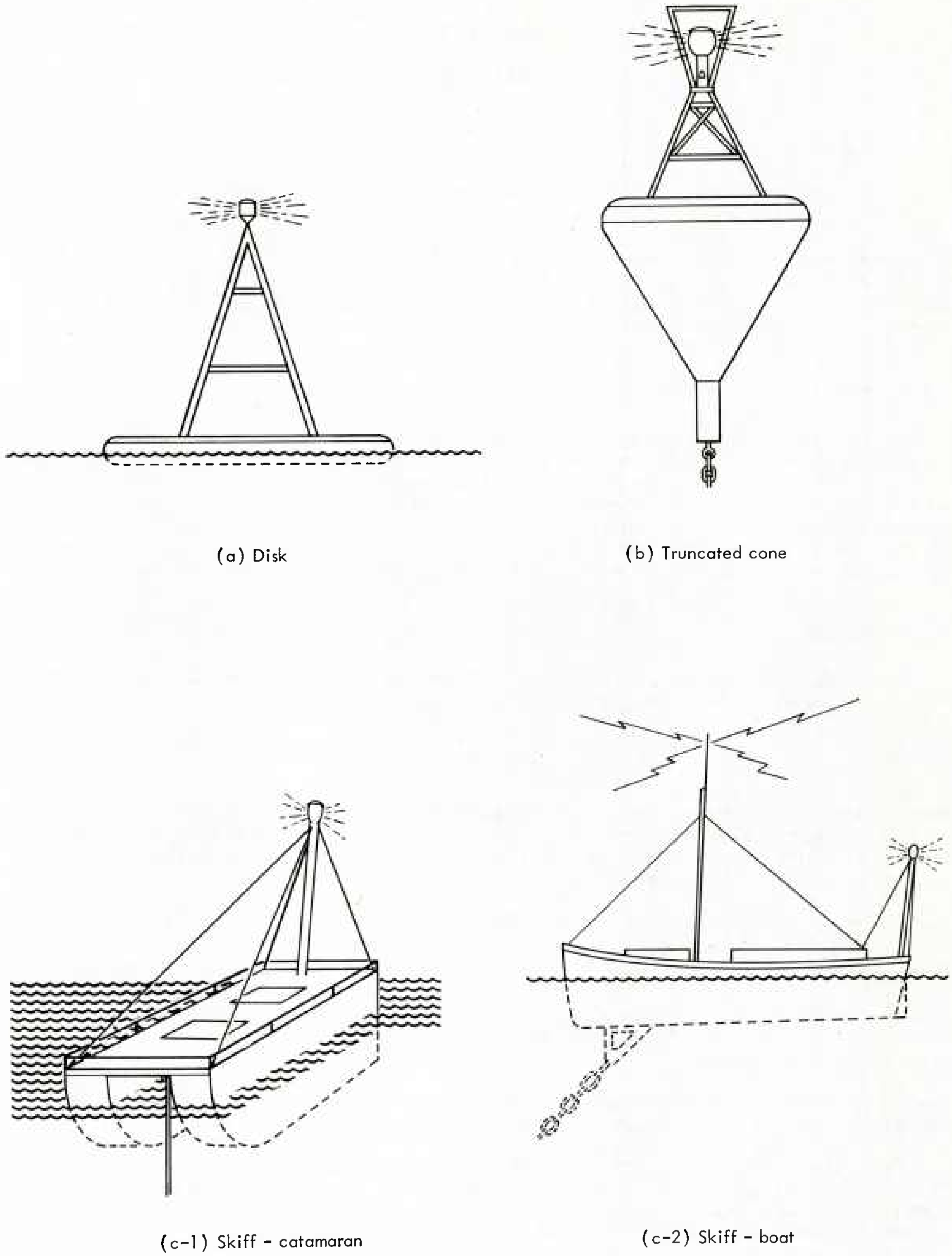
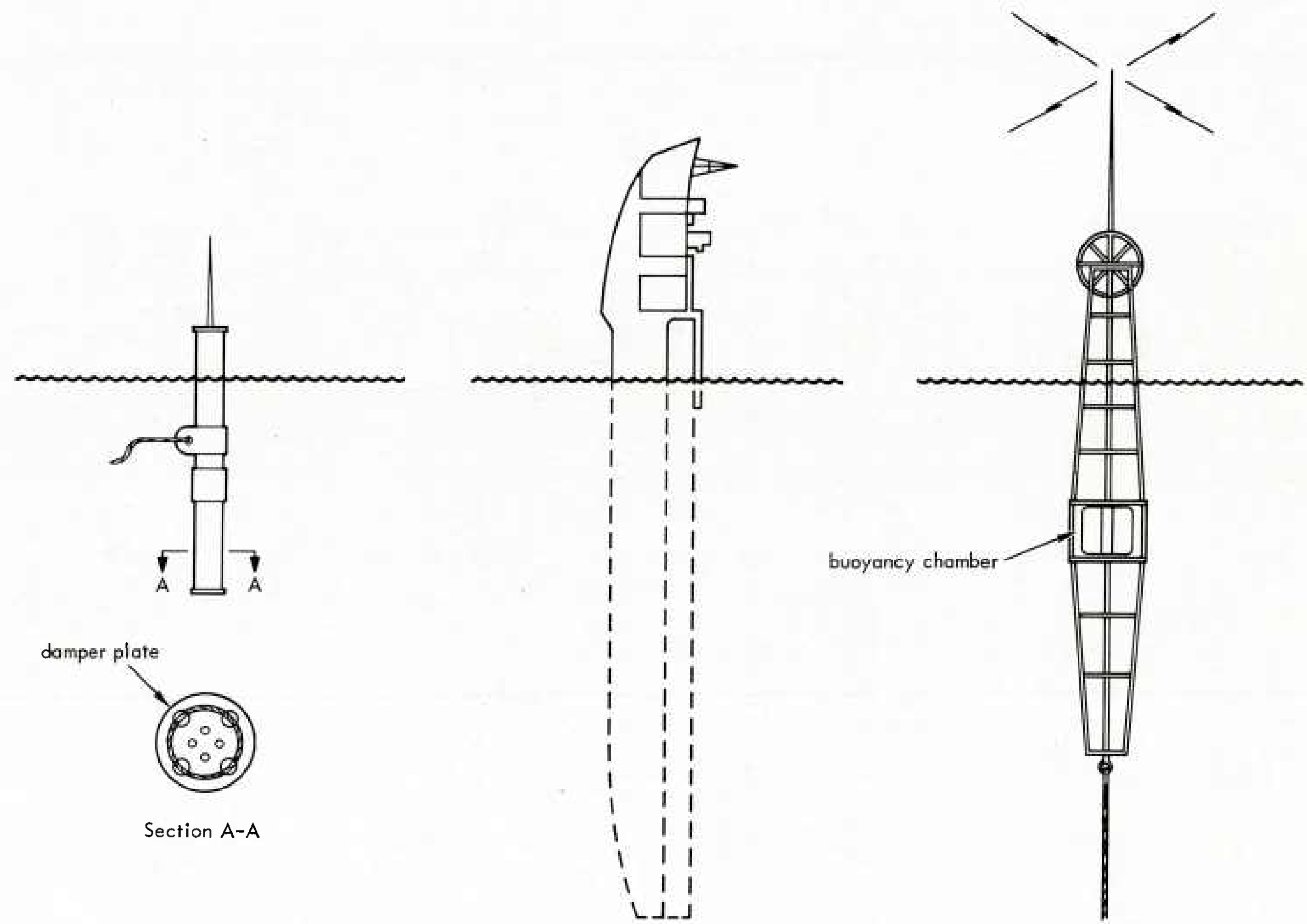


Figure 1-1. Representative types of moored buoys - surface-following.



(a) Spar (with damper plate)

(b) Spar (manned)

(c) Submerged buoyancy chamber

Figure 1-2. Representative types of spar-shaped buoys.

1-6. Truncated Cone-Shaped Buoys. Since truncated cone-shaped buoys are standard in the U. S. Coast Guard and other organizations, design and fabrication procedures do not vary greatly. Cost for a standard truncated-cone buoy, 8 feet in diameter, is approximately $3, 000. Such buoys do not tend to capsize unless an excessive amount of gear is placed on them. However, they are subject to heave, resulting in rapid accelerations and decelerations. They also have a strong tendency to roll excessively as they ride with the waves.

1-7. Skiff Buoys. Skiff buoys include barges, boats, catamarans, and plank-on-edge types, and may be sufficiently large and sturdy to support much gear and instrumentation. They have strong surface-following characteristics and tend to align themselves with wind, wave, and current action. However, they may capsize, are subject to heave, pitch, and roll, and are generally expensive to build and maintain. A skiff buoy 12 feet long with necessary appurtenances is estimated to cost about $15, 000. Maintenance is a continuing problem because of the relative complexity of the structure involved.

1-8. Spar-Shaped Buoys. Buoys in the shape of a spar lend themselves to stabilization. Heave or vertical excursion can be minimized if the spar is made long enough to negate surface wave motion. Because a spar may move up and down, out of phase with wave action on a servicing vessel, difficult problems of attendance can occur. Spars are excellent for maintaining vertical position with minimum angular motion. However, thorough understanding of the motions of tethered spars in deep water is lacking. There is a possibility they may become unwieldy under such conditions.

Spar buoys (Figure 1-2a and b) range in size from a simple 20-foot-long, moored log of red or northern cedar equipped with reflectors as navigational aids (U. S. Coast Guard, 1953) to free-floating and moored types over 400 feet long, such as FLIP and SPAR (paragraph 1-19), with living and working accommodations for many men. To attain and maintain vertical orientation, spar buoys are ballasted below the water level either by means of flooded compartments and/or ballast weights affixed to their lower portions. Some taut-line moored sparlike buoys have buoyancy chambers near their midsections (Figure 1-2c).

Costs of spar buoys are directly related to size, materials, purpose, and type of construction, and can vary from less than $100 to hundreds of thousands of dollars. On a basis of size, spar constructions are believed to be more economical than skiff types. In the final analysis, however, it is the purpose of the installation and the application to which it is put, not the cost factors, that determine the choice of type. A treatise on the stability characteristics of various buoy configurations is provided by Kerr (1964).

1-9. Subsurface Use.

Spheroid-shaped buoys are used primarily beneath the surface because their configuration enables them to withstand pressure. As with surface buoys, subsurface spheroid buoys may vary considerably in shape while retaining their essential principle. They include cylinders with rounded or flat ends, oblate spheroids, true spheres (Figure 1-3a, b, and c, respectively), and many variations of these shapes.

In depths to 1, 000 feet, less spherical shapes can be used. As depths increase, use of the true sphere becomes increasingly mandatory. At depths below 3, 000 feet the true sphere is virtually required for reasons of structural strength and practicability of construction. Although the sphere shape has a high drag factor, the problem of ocean current drag can usually be overcome by constructing a pressure-equalized clamshell housing (Figure 1-4). Spheroidal buoys have been constructed of steel, aluminum, and glass. Glass and aluminum spheres have been used at depths of almost 20, 000 feet.

The necessity for achieving high-quality close-tolerance construction makes sphere buoys expensive to fabricate. As cost examples, 22-inch-ID aluminum spheres used at 17, 500-foot depths may cost $800 to $1, 000, or approximately $10 per pound of buoyancy. Aluminum spheres of 38-inch diameter good to about 7, 000-foot depths cost around $300, approximately $1 per pound of buoyancy. Smaller glass floats 8 to 12 inches in diameter cost about $200 each (Benthos, 1964).

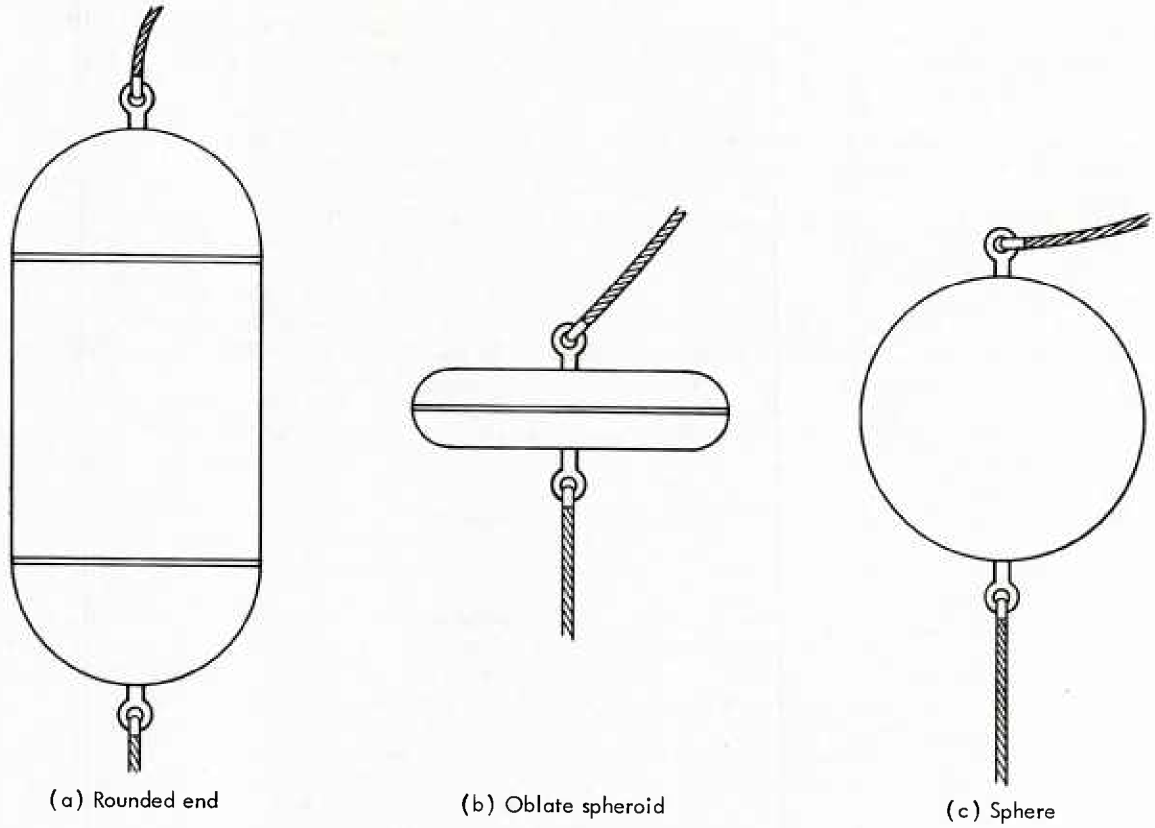


Figure 1-3. Representative types of moored buoys - Submerged.

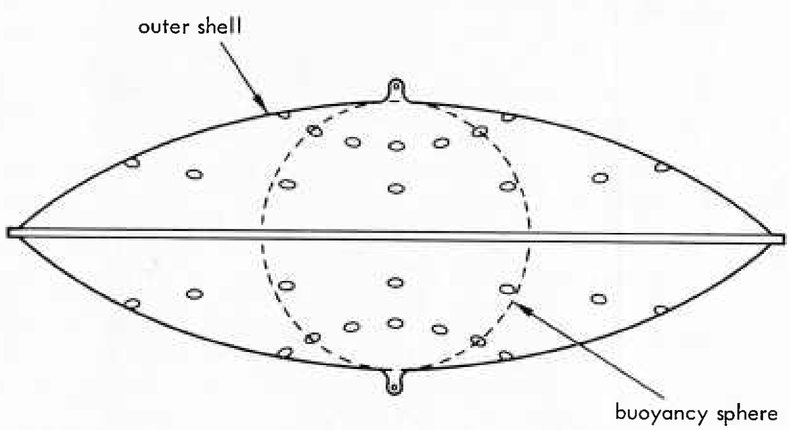


Figure 1-4. Submerged buoy with pressure-equalized clamshell housing to reduce drag.

Spherical buoys present handling and installation problems. Attachment of handling gear is difficult. Slight damage or indentation suffered by a sphere while being handled at or near the surface may be highly amplified at great depths.

Investigation is underway to develop solid flotation materials that can be used as floats or buoys in very deep water. These could be molded into shapes that might be more convenient than spheres in some situations. Also, they would not be as susceptible to damage, and consequently handling characteristics would be better. One material, syntactic foam with about an 0.8 density, is reported to be suitable for use indefinitely at pressures to 18,000 psi with a safety factor of 1.5 (Costello, 1963-64). At these pressures, it deforms less than 0.7 percent. At present, syntactic foam would provide buoyancy at a cost of about $5 per pound. As evident, cost is a factor in developing solid flotation materials for use in deep water. Another chief problem lies in finding a substance light enough to provide a high buoyancy-to-weight ratio yet sturdy enough to resist extreme pressures, all without being bulky. Low buoyancy-to-weight ratio usually means that large bulk is needed, and this creates problems through the need for valuable stowage space and the increase in handling difficulties.

1-10. FABRICATION.

1-11. Materials.

The materials commonly used for constructing buoy frameworks, hulls, and shells are steel, aluminum, and various synthetic products. The steel used has generally been of structural grade, for example, HY-80 or HY-100. Such steel has good workability and weldability, though welds should be x-rayed for safety. These steels are not corrosion resistant and require paint or other protective coating. Relatively new types of steels, such as those classified as T-1 and T-1A, also provide desired high-yield strengths to 100,000 psi. At the present stage of development special noncorrosive steels and special processes such as galvanizing have not proven justified. Longevity of buoys is not known to be improved by such processes and materials. Welding problems arise with special steel and additional expense is involved in special processes.

Success has been achieved with aluminum construction for buoys and oceanographic instrument housings just as it has for ship and submarine hulls. Welding and welding inspection methods for aluminum are well established. Aluminum alloys are widely used for pressure vessels because they are highly resistant to corrosion. For pressure vessels under either internal or external pressure, the rules of the boiler and pressure vessel code of the American Society of Mechanical Engineers may be followed in conjunction with statutory and regulatory requirements that may affect the use of the vessel. The allowable stress values and design charts in the ASME Code were prepared to provide a safety factor of at least 4 against burst or collapse, and one of at least 1.5 against excessive deformations by yielding. Aluminum alloy type 7075-T6 is good for construction of subsurface buoys due to its high strength and exceptional resistance to corrosion. Aluminum alloy type 6061-T6, most commonly used for buoys, is practical in both surface and subsurface types.

Synthetic products that appear versatile and practical for construction of surface and shallow submerged buoys are the glass fiber-epoxy laminates. These are used to enclose a framework or configuration that may be made from polyurethane foam or steel. The fiber glass laminates are not as tough and durable as metal and can be punctured and damaged more readily, but they are inert materials, easily fabricated and formed, do not readily attract marine growth, and resist adverse effects of the environment. The polyurethane foam often used inside fiber glass laminate-covered buoys can be made in densities ranging from about 1.5 to 20 pcf. It usually weighs about 2 to 3 pcf. The foam is unicellular (closed cell) and has an absorption factor of about 4 percent.

Glass and ceramics apparently offer excellent potential for application in the construction of deep submergence buoys in the near future. As reported by Stachiw (1964), valuable properties possessed by these materials include compressive strength in excess of 300,000 psi, moduli of elasticity varying from 8 times 10^6 to 50 times 10^6, linear elastic behavior, impermeability to water, and thermal expansion rates of 6 to 75 times 10^{-7} inch/inch°F. In addition to fiber glass-epoxy laminates, flake glass-epoxy laminates have been developed that are superior in some respects. Notch sensitivity and permeability to water is lower and machinability of external surfaces is better.

Furthermore, sphere glass-epoxy composite materials have been developed that are lighter than water. By selecting the right size of glass spheres, from 30 to 300 microns in diameter and 2 microns in wall thickness, and proportioning them properly with epoxy resins, it is possible to achieve composite material densities of 22 to 45 pcf, with compressive strengths varying correspondingly from about 2,500 psi to 20,000 psi. Thus, though the compressive strength is low, the fact the material is lighter than water permits the cross section of a shell to be as thick as desired without appreciable decrease in buoyancy.

1-12. Construction.

The interior construction of buoys has generally been one of three types: hollow-pressurized, foam-filled, or compartmented. Hollow-pressurized construction is used for submerged buoys. This type of buoy consists of a relatively thin shell with a minimum of interior reinforcement and cross bracing. The shapes used range from the true sphere to cylinders with rounded ends. Sizes are limited to maximum dimensions of about 4 feet because of the large pressures involved. Pressurized construction is advantageous for use at depths to approximately 3,000 feet, since it permits the shell to resist large external pressures. However, because of the difficulty of keeping air under high pressure and the consequent danger of explosion, pressurized construction is not suitable for long-term use or for use at depths where internal pressures of more than 2,000 psi are required.

Foam-filled construction provides protection against sinking even when a buoy is punctured or otherwise damaged severely. Crystallized foam reinforces the basic configuration and, as mentioned above, can be used as a form about which to construct a buoy shell economically. After being molded into the shape desired, the foam is generally covered with a fiber glass-reinforced plastic sheathing. Though the foam used for buoys is firm and resists compression, its use is limited to depths of moderate pressure, i.e., around 1,000 feet. In constructing a buoy of foam and fiber glass, two methods are followed in applying the fiber glass to a form - hand layup and machine sprayup. Hand layup is the process of applying fiber glass in woven rovings by first painting the surface with resin-catalyst bonding and then laying on a sheet of fiber glass. The process is repeated until the desired thickness is attained. The machine sprayup process uses a double-barreled pressure gun, projecting particles of fiber glass from one barrel and simultaneously projecting a resin-catalyst bonding agent from the other barrel. This process also is continued until the desired thickness is obtained.

Compartmented construction is used in larger buoys to provide insurance against sinkage and loss should punctures occur in one or more sections. An additional benefit is that the partitions and their reinforcements add rigidity and structural integrity to the buoy structure. For extra safety and reliability, the compartments can be filled with foam of the same or similar type previously described. Compartmentizing a buoy increases its cost 20 to 30 percent, but this is justified when the cost of replacing a buoy system and its assorted instruments and gear is considered.

1-13. TYPES.

It is beyond the scope of this chapter to discuss all types of buoys. Here they are considered as (1) conventional buoys and (2) deep ocean buoys, with emphasis on the latter.

1-14. Conventional Buoys.

Conventional buoys are those used in various navigational-aid and ship-mooring functions. Their placement has been primarily in shallow waters of less than 200-foot depths to mark the entrance to channels, to warn of sunken hazards, and to provide permanent secure anchorages in harbors. In general, well-established shapes and methods of construction have evolved.

Standard references exist covering the requirements and criteria for conventional buoys. Among them are the Bureau of Yards and Docks design manual (BUDOCKS DM-26) published by the U.S. Navy (BUDOCKS, 1962), and the U.S. Coast Guard "Aids to Navigation Manual," chapter 30, (U.S. Coast Guard, 1953). In these, the principal conventional buoys are identified and major features and functions discussed. Here, only a few conventional buoys, those deemed most significant for deep-ocean construction work, are considered.

1-15. Navigational Buoys. Navigational buoys are used in positions where an aid to navigation is needed, but a fixed structure is impracticable. Navigational buoys can be considered in two broad groups: (1) common buoys and (2) special-feature buoys.

Principal types of common buoys are nun, can, and spar. Though variations exist, the basic shapes of these types are shown in Figure 1-5a, b, and c. Common buoys are employed as markers and are painted in numerous patterns and colors with coded significance. They are generally constructed of steel, though other materials may be used.

Principal types of special-feature buoys are bell, light-and-bell, whistle, light-and-whistle, gong, and light-and-gong. These are more complex than common buoys because of structures that must be mounted on them and the necessity for greater stability to permit light and sound features to function properly. As with common buoys, there are many variations in construction and shape. However, the two basic configurations shown in Figure 1-5d and e, lighted whistle and lighted bell, are representative. Special-feature buoys are nearly always constructed of steel. Normally, the conventional special-feature buoys are too expensive for deep ocean applications. Instead, the special features may be modified or otherwise adapted to the buoy design for a particular deep ocean installation. For example, the U. S. Navy Oceanographic and Meteorological Automatic Device (20 by 10-foot platform, unmanned) buoy, called NOMAD, is equipped with a mast supporting a flashing light and a bell.

1-16. Mooring Buoys. Mooring buoys are used to provide safe, secure, precisely located anchorages in harbors and other areas where ships pause between sailings. So used, they eliminate the need for ships to utilize their own anchors. Mooring buoys generally are of four basic types shown in Figure 1-6, cylindrical, peg-top, pear-shaped, or wooden. They are most commonly constructed of steel plates welded or riveted together, though wood and other materials may be used. Mooring buoys vary in size depending on the class and type of anchorage for which intended.

Mooring buoys support chains and other gear associated with anchorages and have attachments to which ships can connect. They must be sturdy and rugged enough to withstand battering by ships, boats, and other floating objects. Typical major features are fenders that surround the buoys at more than one level to protect the buoy and vessels coming alongside, and a railing to minimize danger to personnel boarding the buoy. The basic construction of mooring buoys makes them rugged and not subject to sinking. Though few deep ocean anchorages of a permanent type have yet been achieved, it is evident that conventional buoys, modified and unmodified, offer good potential for deep ocean application. The TOTO II installation is an example of mooring buoys being used in a deep ocean installation (paragraph 4-11).

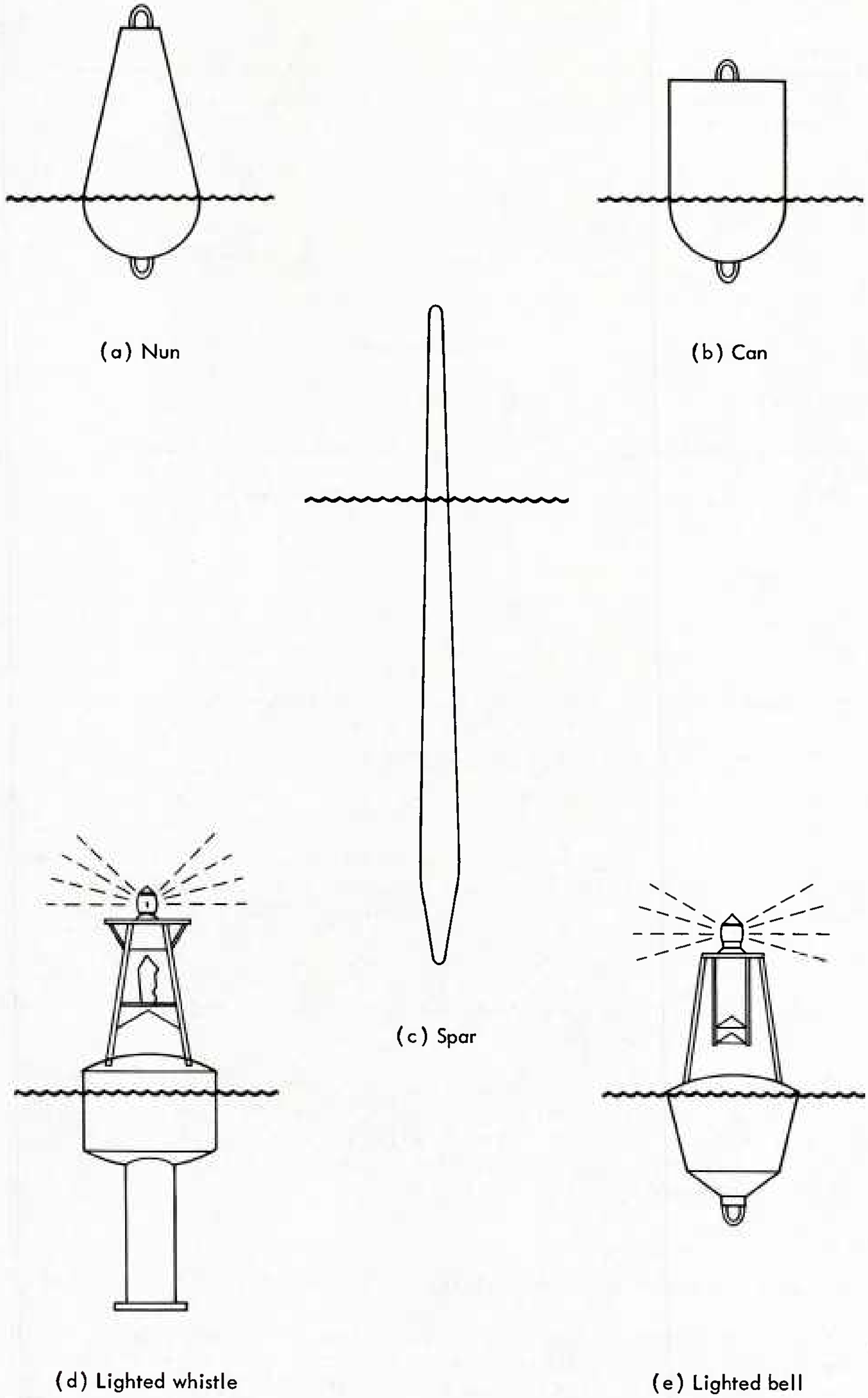
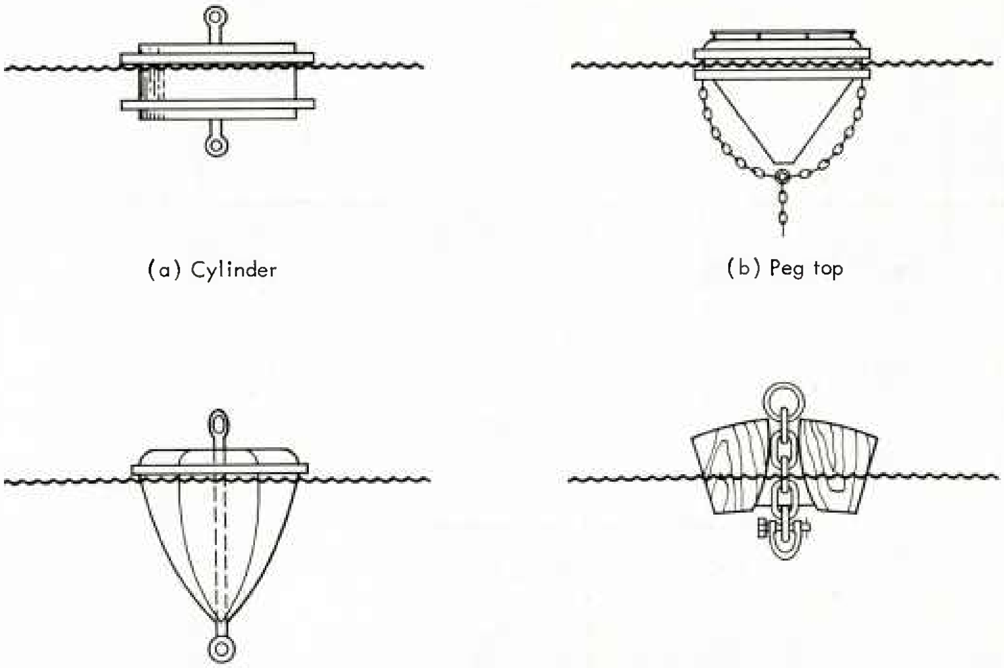


Figure 1-5. Principal types of navigational buoys.



(a) Cylinder
(b) Peg top
(c) Pear-shaped
(d) Wooden (in section)

Figure 1-6. Basic types of mooring buoys.

1-17. Other Types. Other types of conventional buoys include marker buoys and net buoys. Marker buoys are connected to the end of submerged chains and other gear that must be recovered for future use. They also mark particular locations such as that of the anchor of a ship or, in the case of fuel-oil moorings, the end of the oil hose. Clearly, these have occasional deep ocean application. Net buoys are used to hold suspension nets which protect ship anchorages from torpedoes. They and similar buoys are also used to support other temporary and semipermanent objects during and after completion of structures in and over water. Obviously, these too may have deep sea use.

Marker and net buoys take many shapes and forms, and their sizes depend upon the amount of buoyancy required of them. Similarly, they can be constructed of many different kinds of material including plastic, wood, and metal. For durability, ruggedness, and toughness, steel spheres appear to be superior to most other kinds of construction. This may be especially true in deep ocean installations.

1-18. Deep Ocean Buoys.

These may be classed according to use as free-floating or moored.

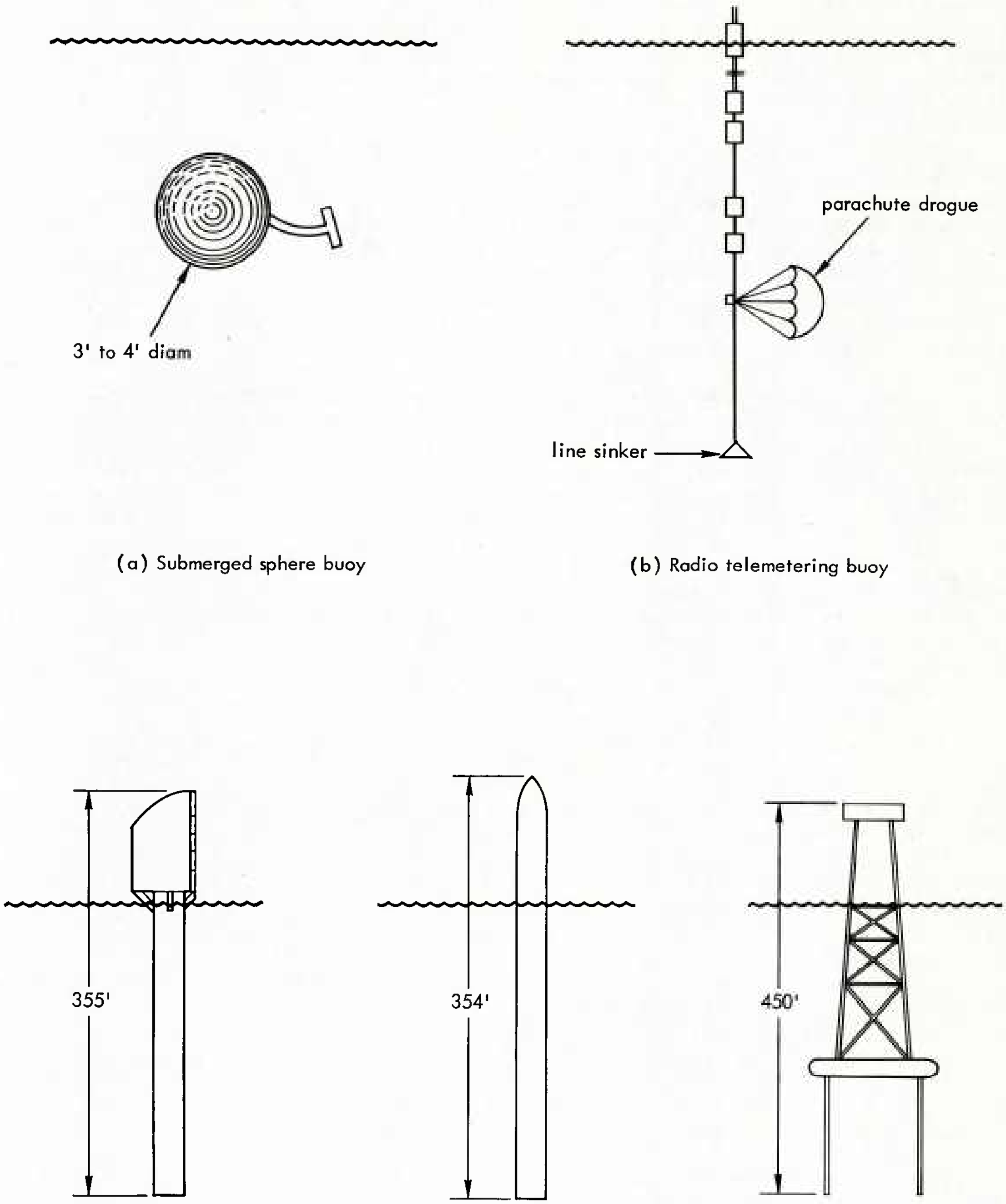
1-19. Free-Floating Buoys. Free-floating buoys of various shapes and sizes are being used in a variety of deep ocean applications, including measurement of wind, wave, current, and meteorological phenomena, and support of manned research stations. Free-floating buoys range in size from a few inches in diameter to large spar buoys hundreds of feet long. They may displace a few pounds or thousands of tons. Representative types of free-floating buoys are shown in Figure 1-7. These include neutrally buoyant floats, small surface floats supporting instruments and other attachments, large spar-type buoys, and large buoyant structures designed as stable platforms to perform numerous research and construction functions. Some of these free-floating buoys have been constructed and utilized. Others are being studied or are under construction.

(a) Neutrally Buoyant Floats. According to Knauss (1962), free neutrally buoyant floats that can be adjusted to float at any depth and are equipped with sound transducers for trackability have been used successfully in deep ocean operations (Figure 1-7a). These are valuable in determining direction and velocity of subsurface ocean currents. They are also useful in conducting research on the influence of temperature, salinity content, density, and other factors that affect acoustical and visual properties of ocean water at different depths and in different locations. The buoys described by Knauss (1962) are constructed of sealed aluminum tubes that are lighter and less compressible than sea water. These properties permit adjustments for flotation at specific depths.

(b) Surface Floats with Suspended Instruments. Free-floating buoys with instruments and other gear suspended beneath them are being used successfully to obtain oceanographic data at various depths. In one application, according to Munske (1964), a telemetering radio surface buoy supports a drogue parachute by means of a stainless steel cable (Figure 1-7b). The buoy is in the form of a steel drum. A damper plate at the end of a section of steel pipe directly below the drum helps minimize vertical excursion. The steel cable suspended underneath, with a 100-pound weight at its end to keep the line taut, holds the drogue parachute. The parachute is set at the depth at which current movement is to be effective in moving the buoy. A weak link positioned in the cable just above the drogue permits recovery of most of the gear if the parachute or anchor becomes entangled on some obstruction. Other instruments to measure currents, temperature, density, and depth may be placed in the line at appropriate intervals. Data recorded is transmitted by a radio mounted on the buoy. Foam flotation material inside the steel drum prevents sinking in event of puncture.

(c) Spar Type. Large free-floating spar-type buoys are an approach to providing stable platforms at sea for all weather and wave conditions. Such buoys can house men as well as instruments. A number of them are contemplated, both manned and unmanned, and some have been or are being constructed. One already constructed and in use is designated Floating Instrument Platform, called FLIP (Figure 1-7c). This buoy is 355 feet long and weighs 600 tons. FLIP was designed to move less than 3 feet up and down, and slightly more than 1 degree from side to side in 30-foot waves. It is so constructed that it can be towed like a barge to its station area, with the forward 55 feet bow-shaped in design to facilitate towing. Once the buoy is on station, the aft end is flooded until it is vertical in the water with 300 feet submerged. The upper section contains living quarters for personnel who man the structure. The long submerged section provides the stability which minimizes vertical and lateral motion, since its natural period is so much longer than that of the waves. The submerged part also permits the taking of measurements at moderate depths, and visual observation of various phenomena at such depths. Early tests of FLIP at sea were highly successful; only a 3-inch vertical movement was experienced. Built by Gunderson Brothers Engineering Company of Portland, Oregon, under contract to the Office of Naval Research, it is now being operated for the Navy by Scripps Institution of Oceanography at La Jolla, California (Munske, 1964).

A second example of large spar buoy is the Seagoing Platform for Acoustic Research, called SPAR (Figure 1-7d). This buoy was conceived and developed at the U.S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland. Its purpose is to study the precise measurement of sound transmission and projection through open sea water. SPAR is similar to FLIP in size and principle of stability, but unmanned. It is 354 feet long, cylindrical in shape, and displaces 1,720 tons when submerged. It is designed to be towed to station and flooded, as is FLIP. Once in the vertical position, it is maintained on station by tethering to a mother ship with a floating line. Equipment scheduled for SPAR includes vertical and horizontal hydrophone arrays, a precision VHF radio direction finder, a gyrocompass, accelerometers, a string of thermistors, and wave-measuring equipment. Data from SPAR is multiplexed for transmission over the floating cable to the tender (Munske, 1964, and Talley, 1964). Further details on SPAR are presented in Appendix A.



(a) Submerged sphere buoy

(b) Radio telemetering buoy

(c) FLIP

(d) SPAR

(e) FORDS

Figure 1-7. Examples of free-floating buoys.

A third example is the Stable Ocean Platform (STOP) described in Marine Engineering Log (Simmons-Boardman, 1963). This is a proposed design that would be similar to, but larger than, FLIP and SPAR. It would be a manned buoy 412 feet long, also towed on station in a horizontal position, then flooded to the vertical. The section extending above the water surface would be 62 feet in length. It is estimated that a steady wind of 110 knots would cause STOP to "heel" only 4 degrees. Its primary function would be to serve as a station in a global satellite tracking network. Other uses might include those of a weather station and an early-warning system for missile launch. For some functions STOP would have to be maintained on station either by a recoverable mooring system or by a propulsion system. In such cases it would not be completely free-floating, and hence would fall into the category of moored buoys.

(d) Large Free-Floating Structures. Large free-floating structures designed for deep-sea operations such as lowering and lifting great loads are being studied and undoubtedly will be constructed and functioning within the next few years. The most notable example of this type of buoy is the Naval Research Laboratory's Floating Oceanographic Research and Development Station (FORDS), illustrated in Figure 1-7e. This giant super-structure will be about 450 feet long, have a maximum horizontal dimension of 240 feet, displace 6,500 tons, and be capable of lifting a load of 450 tons and lowering it to a depth of 6,000 feet. FORDS is being designed primarily for acoustic transducer evaluation. It also will have other uses such as detection and study of long-wave-length ocean phenomena and operations involving lifting large weights at sea. The status of FORDS is that between feasibility study and design state. J. Ray McDermott and Company of New Orleans is performing the task under a Naval Bureau of Yards and Docks (BUDOCKS) contract (Munske, 1964).

1-20. Moored Buoys. Moored buoys are vital tools in the rapidly expanding field of deep ocean investigation. Large and small, manned and unmanned moored buoys are in existence, under construction, or planned. Some are similar in shape, size and construction to the free-floating type. Problems of attaining adequate stability, buoyancy, and ruggedness, as well as problems of maintaining station to required degrees of fixity, permanency, and reliability, are acute and not satisfactorily solved. Moored buoys fall into one of three categories, as described in the following paragraphs: surface-following, stable, and submerged.

(a) Surface-Following. Surface-following buoys tend to move vertically with the rise and fall of wave action. To date these have been used as markers, support platforms for sophisticated instruments, targets in test programs, and components in experimental anchorage systems. Depending upon their purpose and application, they range in size and shape from small-diameter spheres to barges weighing 100 tons or more. In general, surface-following buoys take one of three forms, disk, inverted truncated cone, and skiff (Figures 1-1a, b, and c, respectively).

(b) Stable. Stable buoys are constructed to minimize heave and pitch for the benefit of scientific measurements being taken, recorded, and transmitted and, in the case of manned buoys, for the comfort and facility of operation of personnel aboard. Two general design approaches have been used to obtain the desired stability. In one configuration (Figure 1-2c), the buoy is so constructed that only a lattice-type network extends above the water surface. This network presents a minimum obstruction surface area to current and wave action. A buoyancy chamber connected to the lattice-work is submerged beneath the surface at a sufficient depth (at least 20 feet) to lessen the effect of wave action and to eliminate the effect of wind action. More construction (or less) may exist beneath the buoyancy chamber. This type of buoy must be maintained in position by a taut-line anchorage system which holds the buoyancy chamber beneath the surface. The second design approach to a stable moored buoy is to utilize the spar design (Figure 1-2a and b). As in the shallow-water and free-floating versions, the principle of the spar is that its period of motion is much greater than that of the waves. Unlike the lattice-work design, it floats freely on the surface and is maintained in position by a semislack line. The spar buoy, generally, can be much larger than the other design. The smaller unmanned spar buoys usually have a damper plate (preferably perforated) suspended or rigidly attached beneath them to further reduce vertical excursion. Attachment of the mooring line is best made near midpoint. The line for longer manned spar buoys is fastened to the bottommost point.

(c) Submerged. Submerged buoys are commonly used to provide tension in taut-line buoy anchorage systems. For this application they most commonly have been installed 50 to 200 feet beneath the surface, though implantations have been accomplished in depths of over 16, 000 feet (Isaacs, 1963). In design, submerged buoys have generally been constructed as spheres, oblate spheroids, or cans rounded on each end (Figure 1-3).

A utilization of moored submerged buoys receiving increased consideration is that at depths of thousands of feet to support or serve as adjuncts to various types of structures pertaining to antisubmarine warfare and other military functions. Information is limited on the accomplishments at these depths. It is known, however, that hollow aluminum spheres have been constructed and submerged to depths of 18, 000 feet. Small hollow glass buoys about 10 inches OD that can withstand pressures at 20, 000 feet are available from commercial manufacturers (Benthos, 1964).

1-21. Pressurized Buoys. Other types of deep ocean buoys include the pressurized kind, both free-floating and moored, configurations of which are illustrated in Figure 1-3. These are generally of three types.

The first includes those filled with liquids of low density, such as gasoline, which develop pressure compensating ambient pressure. Usually such buoys enclose the liquid in a semirigid vessel of synthetic rubber or other flexible plastic material. They can be designed to descend to any depth. (An example is the bathyscaphe TRIESTE.) However, they are bulky, difficult to handle, the shell is fragile, and the flotation material is highly flammable.

The second type of pressurized buoy includes those made structurally strong enough to withstand heavy pressures. These are sometimes reinforced with cellular gas-absorbent material. They are expensive. As size increases, they necessarily become very heavy and cumbersome to handle.

The third type includes buoys with medium-thick, high-strength shells that enclose gas under high pressure. These are useful to moderate depths. However, special equipment is needed to transport them, and they are subject to explosion with subsequent danger to personnel and equipment.

1-22. ACCESSORIES.

1-23. Appurtenances and Attachments.

Most buoys of all types are fitted with appurtenances and attachments, both underneath and atop the structure, to enable them better to perform their functions. Superstructures are commonly mounted on buoys to support or house antennas, navigational instruments, power equipment, and instruments. Usually these are of steel or aluminum welded framework construction. The framework may be enclosed by metal or fiber glass sheathing, depending on its purpose. A characteristic buoy attachment is a steel mast, intended to support and house antennas and navigational aids. These and other attachments are described in the following paragraphs.

1-24. Antennas. Antennas on buoys, used to transmit and receive radar and radio signals, should be short and stiff as to structure, and thus capable of withstanding significant elastic deformation by presenting a minimum area to the wind. From an electrical standpoint, they should be tall, to ensure minimum losses in the loading coil. A compromise between these two ideals is obviously necessary. In actual practice, antenna height varies from 6 to 10 feet.

Center loading of the vertical whip is preferred because the base of the antenna is close to the waterline. A loading coil wound on a ferrite cylinder has been developed. It is a small-diameter, flexible, low-loss coil around which a fiber glass whip can be built. The cone is constructed of a number of short, coaxial ferrite tubes separated by elastic vertebra-like disks. Thus, sufficient flexibility and a reactance adequately independent of deformation are achieved (Walden, 1964).

1-25. Navigational Aids. Other appurtenances and attachments often found on buoys are those serving as aids to navigation. Examples are radar signals, lights, and motion-actuated bells and/or whistles.

(a) Whistles. Whistles are of two- and four-ball types, both similar in operation. The whistle is operated by the up-and-down motion of the buoy in a seaway. Air is compressed in downward movement of the buoy and allowed to escape through a 1/32-inch aperture in the whistle tube, blowing the whistle. On the upward movement, the partial vacuum created in the whistle tube causes the cork balls to lift. Air is again drawn into the tube, compressed on the downward movement of the buoy, and the operation is repeated.

(b) Radar Reflectors. These are employed on buoys to reflect the transmission beam of the searching craft. Success has been achieved at distances up to 8 miles. Turbulent seas reduce range. The radar reflector can be constructed of three concentric 2-foot-diameter circular bands each perpendicular to the other, mounted 6 feet or more above the buoy on a stable frame. The reflector serves not only as an aid to navigation, but also facilitates locating the buoy should it become separated from its mooring. A type of buoy-mounted radar reflector is shown in Figure 1-8.

(c) Lights. Lights on moored buoys fall into two categories: gas and electric power. Acetylene gas compressed in tanks formerly supplied the power for gas lights. Acetylene is being phased out by U. S. Coast Guard in favor of the battery-powered electric light. Batteries are contained in compartments in the body of the buoy. Lights on buoys generally operate to a preset color and frequency series prescribed by laws and regulations pertaining to a specific location. In event of bulb failure, the systems are designed to automatically switch on new bulbs. Batteries must be serviced at predetermined intervals. Range at which lighted buoys can be observed depends on intensity of light and height of light above sea level.

1-26. Instruments. Among the recording instruments commonly attached to buoys are anemometers, current meters, tension recorders, and wave sensors.

(a) Anemometers. These instruments, used to measure wind speed and force, are mounted on the superstructure of surface buoys well above waterline in an area affording greatest amount of freedom from interference by adjacent structural members (Figure 1-9).

(b) Current Meters. Current meters (Figure 1-10) measure velocities of ocean currents. One or more may be suspended at different depths, either by attachment to a mooring line or on an independent instrument line. The meter records, or transmits for recording or telemetering, data collected by it. Current meters are discussed further in chapter 3.

(c) Tension Recorders. Determining and recording the tension of a mooring line is important in defining the performance of the mooring and in estimating its probable life. A tension recorder to provide such data (Figure 1-11) was designed for moored buoys (Richardson, 1963), converting the mooring tension to hydraulic pressure. The whole instrument is used as a tensile member in the mooring and must be located near the top because the piston is forced in by ambient hydrostatic pressure in opposition to the pressure generated by tension. The pressure is recorded on film by replacing the pointer of a pressure gage with a binary disk and transmitting with light pipes. Alternately, a pressure potentiometer is used with a small strip chart recorder.

(d) Wave Sensors. These instruments are used to measure height, magnitude, and period of waves. An example of one type of wave sensor is an instrument suspended approximately 43 feet below sea surface where ambient pressure is about 19 psi. At this depth the transducer in the unit can measure a 30-foot wave without exceeding its range. The wave sensor in the unit is mounted in an oil bath sealed from the water and connected to a strain-gage-type pressure unit. This type of sensor is known as an absolute-gage wave sensor. More information on wave sensors is presented in chapter 3.

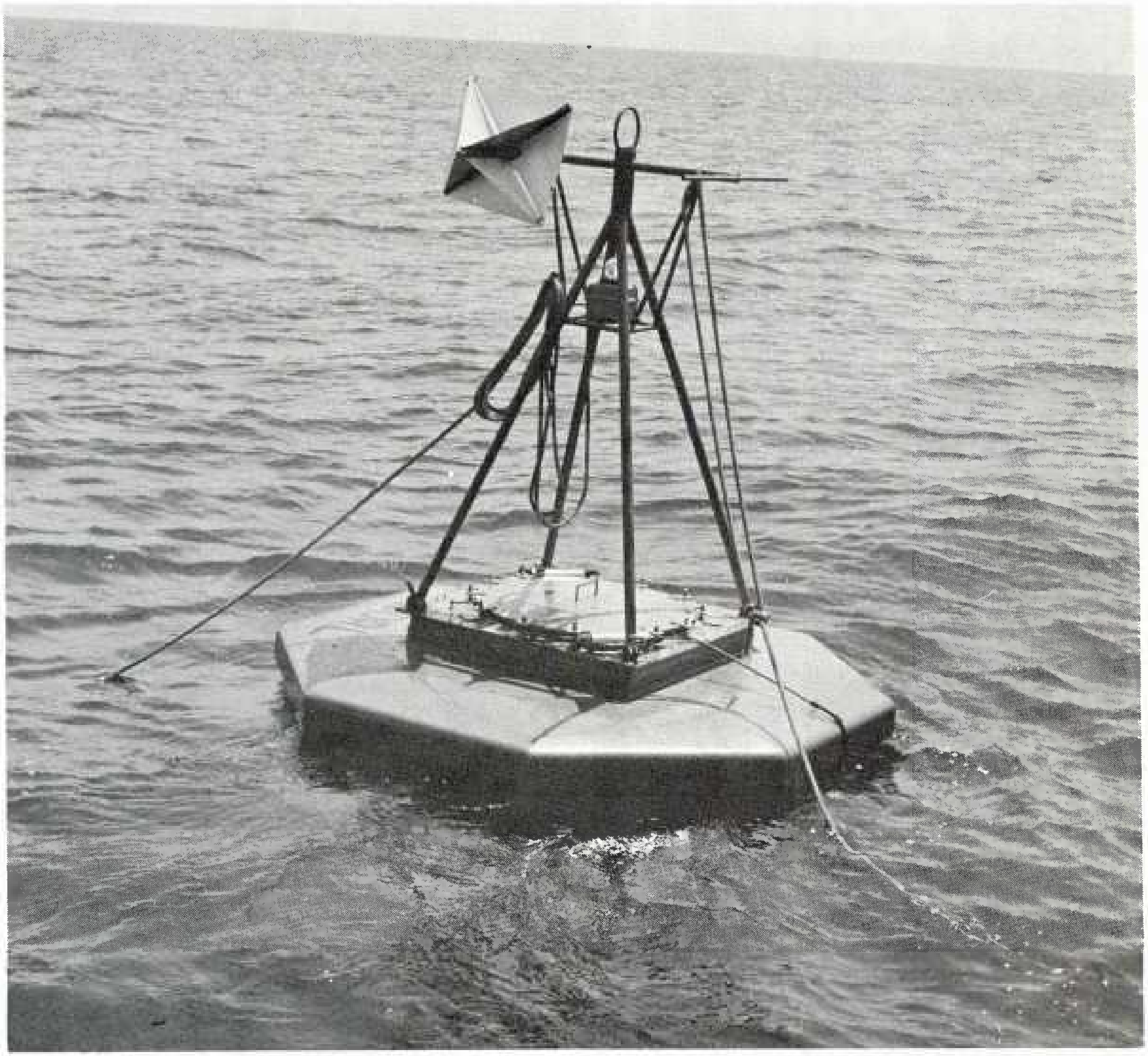


Figure 1-8. Buoy-mounted radar reflector.

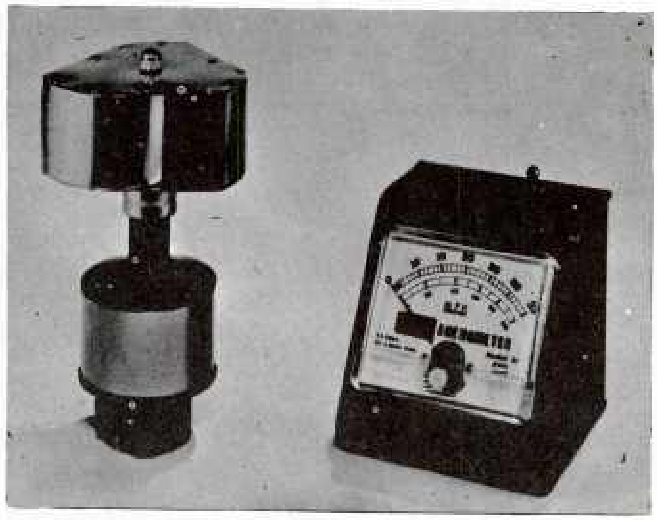


Figure 1-9. Commercial type of recording anemometer for buoys.

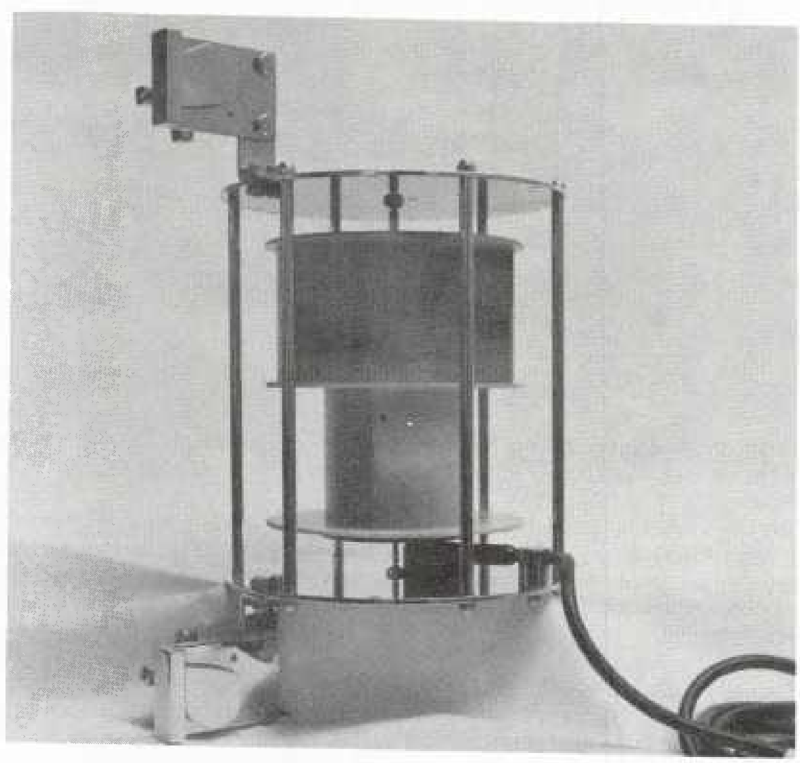


Figure 1-10. Commercial type of current meter.

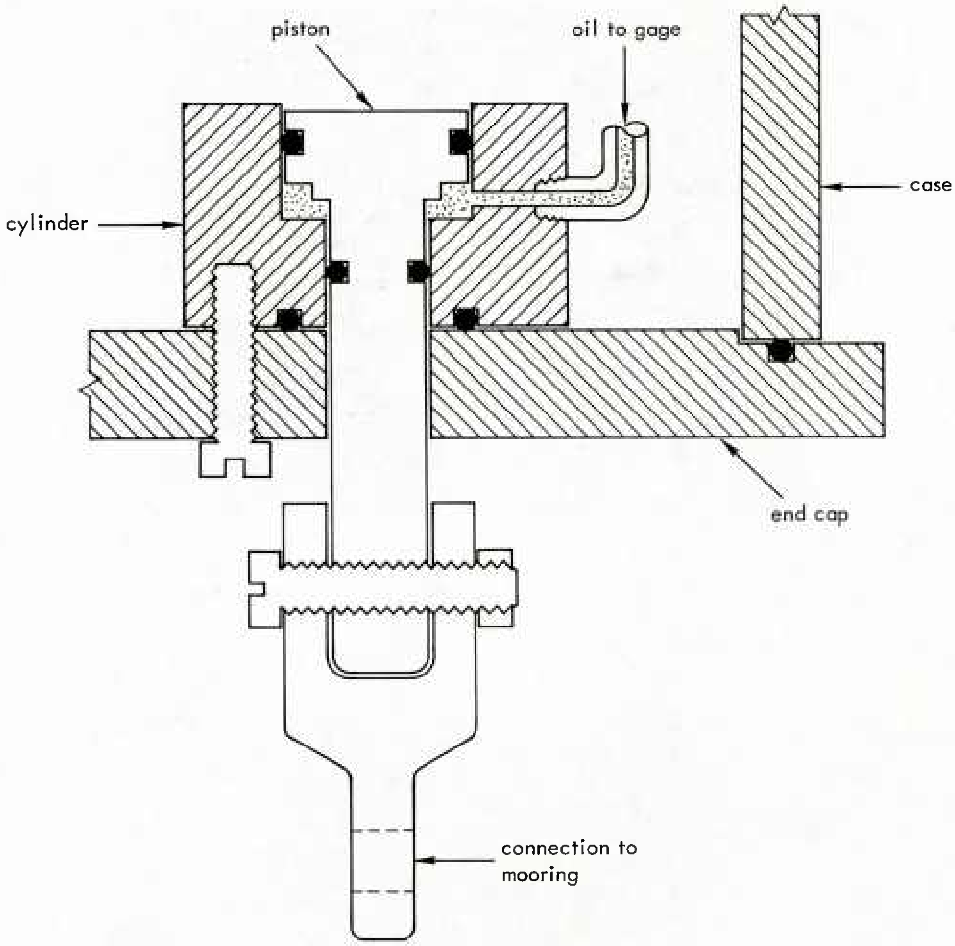


Figure 1-11. Tension-to-pressure transducer.

1-27. Miscellaneous Attached Hardware. Various items of hardware attached to buoys serve such purposes as connecting elements, excursion reducers, and stabilization aids.

(a) Bridles. Bridles may be fastened to buoys as the connecting element between the buoy and its anchorage system, thus minimizing wear at the connection points and reducing hindrance to movement by the buoy. Chain bridles have been constructed so that four chains at dispersed points around the buoy are united at one point beneath it. Structural frame bridles have been used on some surface buoys.

(b) Damper Plates. These are attached or suspended under some types of buoys to attenuate vertical excursion due to surface wave action. A suspended damper plate reacts only against upward movement, while a plate attached to the buoy by a rigid bar reacts against buoy movement upward or downward. In either case the plate should be far enough beneath the surface to avoid influence by near-surface wave motion. A minimum of 50 feet is usual. The plate is generally perforated.

(c) Ballast. Ballast is used to help stabilize some types of buoys and to regulate freeboard. It may be a weight attached to, or an integral part of, the bottom of a buoy which helps maintain the buoy in a vertical position. Ballast may also be established by flooding submerged compartments. This is particularly true on spar buoys that have submerged areas deep in the water.

1-28. Power Sources.

Power supplies for deep-ocean buoy systems are subject to stringent requirements. They must operate for long periods unattended and without replenishment, possess high-energy density per weight and volume, and be safe, reliable, and inexpensive. Other requirements may include the capability to endure extremes of temperature and motion and to function in a silent manner. According to Daubin (1964a), power sources that have been tried in the deep ocean include nuclear, storage battery, lead, silver-zinc, nickel-cadmium, silver-cadmium, thermoelectric, internal-combustion, and wind-driven.

Power sources that might be tried include primary batteries, sea-water cells, and solar cells. Sources utilizing free energy provided by nature appear promising, but disadvantages need to be overcome before such sources are practicable. For example, solar cells, wave motion generators, wind generators, and tidal current generators each must be coupled with a storage battery. Also, necessary mechanical devices are subject to failure. Furthermore, bird lime, salt spray, and humidity work to shorten the life or lower the output of a power array. However, sea-water cells are under study as feasible power sources. At the present stage of development, life of the cells is too short and power output is too little to be of practicable use (Hitchcock, 1964a).

Carbon-powered cells, with a prospective energy-cost of $2 to $3 per kw-hr, appear promising. However, these require more space and weight than do air-depolarized batteries of equal energy capacity. Special low-self-discharge storage batteries are reliable but heavy and expensive.

A device has been designed and tested which produces useful power by reaction to pressure phenomena associated with pressure waves. As reported by Silvers (1964), the unit is designed to operate totally submerged and unattended for 2 to 3 years. It is believed system costs may become as low as $6 per kw-hr, with a lifetime energy output of over 25 w-hr per cu in. of hardware volume. Tests demonstrated an apparent conversion efficiency of 33 percent. In normal operations, efficiencies of about 60 percent might be attainable.

Nuclear power source devices for a variety of space and terrestrial uses have been under development for several years by the Atomic Energy Commission. The devices are included under the general title SNAP (Systems for Nuclear Auxiliary Power). These devices have been built and tested for use on buoys with apparently good results. Stringham (1964) reports that strontium 90-fueled SNAP thermoelectric generators have accumulated more than 7 years' continuous operation without failure. It is believed that the next generation of long-life terrestrial SNAP generators will operate at a cost of $10 to $30 per kw-hr for 10 years or more of continuous maintenance-free operation.

Power from lead-acid batteries costs from $10 to $12 per kw-hr, if the batteries are recovered for recharge. A 12-volt, 2,000-ampere-hour (24 kw-hr) rack of lead-acid buoy batteries would weigh 2,500 pounds. Air-depolarized primary cells perhaps offer the best available power source. A 12-volt 5,000-ampere hour (60 kw-hr) buoy battery package weighs about 1,200 pounds. Power from these batteries would cost about $8 per kw-hr.

Investigation of power sources is continuing. Final evaluation of the sources mentioned is impractical at this time.

PART 2
ANCHORAGE DESIGN

2-1. GENERAL.

In this chapter the term "anchorage" is used to define the complete anchoring system - the site, the ground tackle, the mooring point, and all connecting apparatus necessary for maintaining any construction in position in the deep ocean. This broad definition is considered necessary because requirements exist for a wide variety of contemplated constructions.

Herein anchorage requirements are classified according to: (1) vertical position of the structure to be restrained, whether surface, submerged, or bottom rest; (2) nature of the required restraint, i.e., lateral, vertical, or rotational; and (3) nature of the lower members of the system, whether single-leg flexible, multileg flexible, or bottom rest.

Present knowledge does not make it possible to examine all facets of these requirements as to design details. Depths of water encountered, amounts and directions of forces to be resisted, and quantities and kinds of materials necessary to meet the requirements are factors that have been little investigated. Experience has not been gained and capabilities have not been developed to the extent that specific guiding design principles can be set forth. However, some criteria used in designs of conventional anchorages and information on both orthodox and novel anchors can be helpful when modified and applied to meet unique conditions. Other information worthy of consideration in design is available from research efforts in which objects such as buoys, barges, and submersible test units are being placed in the ocean.

In this part are presented basic considerations for design that may logically apply to both conventional and deep ocean anchorages, such as means of securing to the bottom and forces acting on a moor. An example of analysis of mooring-line catenary configuration as used in the second Tongue of the Ocean anchorage installation (TOTO II) is given. Miscellaneous information considered pertinent to design is summarized. In part 4, accomplished installations are described that exemplify the present state-of-the-art of designing and constructing deep ocean anchorages of various types.

2-2. BASIC CONSIDERATIONS.

2-3. Securing to Bottom.

Other than in the case of "dynamic positioning" (paragraph 4-13), an anchorage system must rely on its attachment to the ocean floor to obtain firm and permanent fixity at one location. Securing to the ocean floor may best be achieved with implements embedded deeply and firmly into the bottom material. Designs of conventional anchorages generally utilize the standard drag-type anchors. Stake piles are sometimes used if fixed bottom anchorage points are essential; however, the capability for placing them in deep ocean application is lacking and they need not be considered further at this time.

2-4. Orthodox Means. The orthodox means of securing to the bottom is by using standard drag-type anchors. These likewise have been used in deep ocean anchorages characterized by liberal tolerances for movement and nonrestrictive bottom area limitations. Present capabilities and equipment for securing to the bottom have practically dictated use of standard drag-type anchors for the larger installations where heavy loads are imposed.

The following information about standard anchors (and their application) is summarized from the Bureau of Yards and Docks design manual (BUDOCKS, 1962). Comments on application to deep-ocean anchorages are included.

(a) Holding Power. Maximum holding power exists when an anchor cable has sufficient scope or length to pull horizontally and the anchor itself is completely embedded. Since an anchor may sink far into the mud, the required scope of chain cable must include allowance for the depth of mud as well as the water depth and the freeboard distance to the chain connection. However, the mud depth and freeboard factors may be insignificant in relation to water depth in most deep ocean locations.

(b) Anchor Drag. Anchors may drag a considerable distance, 50 feet or more, before embedding enough to develop full holding power. In a spread mooring the chain and anchor legs adjust themselves by dragging until each anchor is carrying its share of the total load applied to the moor. In very deep water (1,000 feet and greater) dragging could be detrimental by upsetting a critical balance among possible intermediate support points in the mooring leg.

(c) Anchor Rotation. Stockless anchors may rotate after reaching their maximum holding power and pullout. Stabilizers are welded to stockless anchors to prevent rotation. Also, it is customary to provide a swivel in the anchor chain adjacent to the anchor to eliminate any twist in the chain.

(d) Influence of Bottom Characteristics. Positive identification of bottom composition will be difficult to obtain for the precise area of a deep-ocean anchor position for some time to come. However, a general identification can be made with present techniques. Bottoms possess the following general holding characteristics as they relate to standard anchors:

Type of Bottom	Comment
Mud or silt	Wide range in holding power
Sand	More consistent holding power than mud or silt. Anchor must dig deeply
Clay	Good holding power. Anchor must dig deeply
Marl	Sometimes unsatisfactory
Coral	Fairly good holding power
Rock	Generally unsatisfactory

For good overall performance, standard anchors should possess the following characteristics: (1) correct angle between flukes and shank for digging in, 35 degrees for sand and 50 degrees for mud; (2) large fluke area for anchor weight; (3) large tripping palms for use in mud; (4) sharp point, thin flukes; (5) a stabilizer or stock to prevent corkscrewing or rotating; plus (6) quick embedment without excessive drag, (7) good efficiency measured by the ratio of holding power to weight, and (8) strength and ruggedness to withstand maximum holding powers, vertical breakouts, and lateral pulls.

Standard drag-type anchors can probably be expected to attain their rated holding capacities in deep as well as shallow water as long as the applied force is near horizontal, preferably less than 5 degrees from the horizontal, but in some cases as high as 12 degrees. Also, there appears to be no absolute limit on the depth of their emplacement, since emplacement is mostly a matter of lowering them until they reach bottom. They are rugged enough to withstand abuse resulting from hard contact with the bottom. For these reasons drag-type anchors will probably be the mainstay for securing large installations to the bottom in the near future. Yet several serious disadvantges are evident concerning them as they apply to deep water use. Foremost among these are: (1) considerable horizontal distance is required to adequately set this type of anchor, necessitating large amounts of rope and gear and a massive mooring complex to make the plant; (2) resistance to uplift is small and minor uplift loads can seriously reduce normal holding capacity; (3) since the anchor offers primarily horizontal resistance, even a group of anchors placed at 120 degrees to each other may not provide the desired restraint for a majority of contemplated structures which will impose large uplift forces.

2-5. Novel Means. Several novel methods to overcome the limitations of drag-type anchors in deep ocean application, especially as to their inability to resist uplift loads, are being investigated. Among these methods are the embedment of anchors by an explosive charge and the drilling of piling into the ocean floor.

(a) Propellant Embedment Anchor. Though not fully exploited, the propellant-actuated embedment anchor, also termed explosive, is within the capabilities of present technology. The following information concerning this type has been extracted from a report prepared for NCEL by Aerojet-General (1964). Several manufacturing firms currently are providing embedment anchors of various configurations in the range of 500 to 15, 000 pounds' holding power capacity. An anchor capable of producing a rated holding power of 50, 000 pounds is being supplied to the Army Corps of Engineers (ERDL) by such a commercial contractor. The same government agency currently is developing an anchor expected to be rated at a 300, 000-pound holding power capacity.

Most explosive anchors in various stages of development today are limited to use in water depths of less than 30 feet, though for the smaller anchors, with holding capacities less than 10 kips, the maximum usable depth is thought to be unlimited. The design considerations associated with depth capability relate to the internal ballistics aspect of design, and present no unusual or difficult technological problems. It is believed that a cartridge-actuated anchor may be designed to function normally in any depth of water, such function being contingent only upon successful sealing of the ballistic system against hydrostatic pressures.

Holding power is related both to penetration depth and the soil composition, and thus may vary widely under dissimilar geological formations. Because of the ballistic energy that is essentially "dissipated" in overcoming high hydrostatic pressures, some degradation in penetration occurs with increased water depth. However, with the appropriate design modification to provide ballistic compensation, an anchor designed to function in 15, 000 feet of water will perform just as satisfactorily as its counterpart which is designed to function at only 5, 000 feet.

Certain sea-floor geological formations exist which at the present time are not compatible with the embedment anchor concept. The most significant of these is the basalt or other igneous rock formation that has been washed clean of all overlying sediment. However, while the larger sediment anchors (50, 000-pound size and up) usually are not specifically designed for use in these formations, they have, on occasion, been able to penetrate the medium and achieve a reasonably high degree of holding-power success. This is due to the tremendous amount of kinetic energy released at impulse loading rates, causing penetration of this type of geological formation. The embedment technique is not feasible for the smaller sizes of anchors, since substantially less kinetic energy is available, nor should it be counted upon in all cases for the larger anchors.

Coral formations do not present particular problems inasmuch as they have a relatively low shatter strength coefficient. Disintegrated coral presents no more difficulty than coarse sand, though holding power cannot be expected to be as high in this medium because it is less dense than sand. Igneous rock formations with a sediment overlay, if not of sufficient thickness, pose a special problem. If the sediment layer is not thick enough to accommodate the anchor projectile in the normal manner, the anchor projectile must penetrate the sediment and still fracture and penetrate the underlying rock. Consequently, its use in this type of bottom is not reliable. Rubble or medium-sized boulders, similar to a cobblestone condition, represent one type of sea floor for which an embedment anchor is definitely not feasible.

Optimum design employing explosive anchors normally will be the smallest, lightest, cheapest, and most convenient anchors for a given holding power. However, a particular anchor can be best in only one medium. If used in a medium other than for which designed, it could prove unsatisfactory from the standpoint of size, weight, or cost. At this stage of development, no general statements can be made regarding the relationship of holding power versus penetration, anchor size or cost effectiveness considerations.

(b) Drilled-In Anchors. Drilled-in anchors, also called foundation-type piles, offer another implement with a broad range of application in deep ocean areas. Much of the information presented here is extracted from a report by Global Marine Exploration (1964). Applications cited therein include bearing and uplift as well as lateral resistance capabilities. The basic emplacement operation of "drilling in the ocean floor" is a demonstrated one, according to Long (1962) and Geofert (1963). Theoretically, drilled-in piling can be installed in any depth of water to the limit of practical use of drill pipe (about 25,000 feet). A more realistic depth limitation appears to be the operating depth capability of available television systems. So far as is known, no attempt has been made to install a closely spaced collection of piles in a depth of more than 1,000 feet. Actual installations of this nature are more likely in depths of 200 to 300 feet.

A conservative estimate of the vertical holding power of cemented piling (smooth surface steel) would be based on a shear value between grout and steel of 75 psi of steel surface. In the event that the bottom shear strength of soil is less than this figure, then the shear strength between grout and soil would govern.

A lateral-loaded piling is less calculable. Lateral mooring loads (in surge) of over 100,000 pounds are not uncommon in a normal anchor pile (13-3/8 in. OD). Piling has been tested by using large winches on surface barges and pulling one pile against another with winch loads as high as 100,000 pounds. Off San Clemente Island 24-inch OD piles were given a lateral test of 45,000 pounds without failure. A recent calculation of the lateral strength of a 30-inch-diameter pile in fairly hard compacted sand indicated a lateral load of 160,000 pounds could be safely withstood. In making calculations or estimates of the expected lateral strength of piling, the diameter of the grout at the top of the compacted bottom soils (not considering silt or soft interface materials) should be estimated at about three times the drilled hole diameter. The designer may assume the point of fixity of the pile to be about 2 feet below the top of cement grout, assuming the grout cannot, or will not, stay in a restrained or molded hole in the bottom once it rises up past the level of compacted materials.

In soft materials of considerable depth, drilled-in anchors normally take the form of deadman anchors. In this case the mooring line is attached in the middle of the length of pile to prevent its rotation. At moderate water depths this type of pile may either be drilled, jetted or driven in; the mooring line attachment is well below the mud line and the line must, and normally will, cut itself down into the foundation.

No evidence is known to exist that the strength of piling decreases with depth of water. Grout has been poured and laboratory tested under conditions existing at a 200-foot depth in salt water. No tests as to what effect very high pressures will have, if any, on the setting of cement are known to have been made.

As to the relation between piling penetration and size of piling, the same principles would apply as in land-driven piling. Larger diameters and longer lengths mean more area and less stress in shear on the grout and between grout and soil.

Bottom implements are discussed further in part 3.

2-6. Maintaining Moorpoint Position.

In design of deep ocean anchorages attention must be directed to defining realistic restraint tolerances and their influence on the loads imposed on all elements of the anchorage. As restraint against rotation and against lateral and vertical excursions becomes more stringent, the complexity of the system increases and loads on the moor are greater for a particular size of structure. Furthermore, not all degrees of restraint desired for contemplated installations are yet feasible or achievable.

In this chapter small structures are considered as those that can be made reasonably secure with deadweights or conventional anchors. All others are classed as large, irrespective of size. Best estimates for small structures tethered by a single-riser system is that the structure can be maintained on station within an excursion radius about the anchor point of 5 to 10 percent of the depth in which it is anchored, down to 20,000 feet. Such a system does not control rotation. Examples of this type of installation are the NOMAD buoy and the anchorage systems for Project DOMINIC (paragraph 4-6). For multileg systems it is estimated that the excursion could be limited to a radius of 5 percent of the depth, to depths of about 10,000 feet. The estimate on rotation control is 15 degrees. However, for small structures at great depths, the multileg system costs, with materials duplication for each leg, become prohibitive in relation to the total installation cost.

Ships have been anchored to great depths using shipboard gear. Although precise tolerance data on these large structures are not available, it is estimated that excursion along the axis between two anchor points could be limited to 200 feet in moderate seas; perpendicular excursion may be of the order of 500 to 1,000 feet, and possibly more. Rotation can probably be restrained to 15 degrees at 10,000- to 20,000-foot depths, and to more precise limits at lesser depths.

A special multileg mooring independent of the ship's own ground tackle has been accomplished to depths of about 5,400 feet (TOTO II installation, paragraph 4-11). This mooring will hold large ships (cruiser size) within an excursion radius of 50 feet on a rigidly fixed heading. But this requires a somewhat ideal location and ideal installation conditions.

Use of the conventional anchor-cable method for mooring vessels has been demonstrated to 20,000-foot depths, according to Holm (1964) and others. The general rule of thumb for scope for anchoring a vessel is to allow five times the depth of water in which it is to be anchored. Holm reports that a system was designed to anchor the MISSION CAPISTRANO, a 17,000-ton vessel, in 20,000 feet of water and to hold position indefinitely. This was accomplished using light buoyant polypropylene line and a 3,000-pound anchor.

2-7. Forces on Moor.

Though conditions for deep ocean anchorages can be unique and exceptionally severe, the underlying causes of forces can reasonably be assumed to be the same as for shallow water anchorages. Thus, a logical source of information concerning design forces on an anchorage is the Bureau of Yards and Docks design manual (BUDOCKS 1962). It is impractical and beyond the scope of this chapter to include the large amount of supporting data in the form of tables and graphs that the BUDOCKS manual contains as potential help in solving formulas. The factors affecting design forces are described here in the context of deep ocean application as a checklist and a guide for considerations. Modification and qualification of the data is left to the discretion of the designer.

BUDOCKS (1962) suggests that the following data on site and vessel are required for design of a fixed mooring: (1) maximum recorded and 5-minute-duration wind velocity at the site; (2) tides and currents at the site; (3) orientation of the moored ship relative to the incident currents; (4) height and direction of approach of maximum waves incident on the moored ship; (5) depth of water at mooring; (6) waterline length of vessel, draft (loaded and light), displacement (loaded and light); (7) projected area (side and end) of vessel above the waterline (light and loaded); (8) propeller area; (9) location of deck fittings; and (10) unusual conditions (floods, hurricanes, ice, exceptional tides and currents).

This information is utilized to determine forces on the moorpoint due to <u>initial impact</u> of a vessel impinging on the mooring during the mooring operation, and <u>forces on the vessel</u> while moored. Evaluation of forces due to the mooring operation should include consideration of the velocity and angle of approach of vessel, and allowance for accidental improper berthing. The energy of impact of vessel may be computed by the following equation:

$$E_t = \frac{WV^2}{2g}$$

where E_t = total energy of impact

W = loaded displacement of vessel (lb)

V = component of velocity of approaching vessel normal to the face of the mooring (or parallel to the mooring cable) (ft/sec)

g = 32.2 ft/sec/sec

For forces on the moored vessel, BUDOCKS (1962) suggests the design of an anchorage normally should provide against the following forces when the vessel is both loaded and light: (1) wind, surge, waves, and current acting simultaneously on the vessel; and (2) wind, surge, current, and ice acting simultaneously on the vessel.

Evaluation of wind and current forces as presented in the BUDOCKS manual is based upon equations relating studies of models to data on prototype-size vessels. Numerous graphs and tables accompany the equations for their practical application.

Considerable surge and swing horizontal force is created when the motion of the moored vessel is checked rapidly by the tightening of the lines as the vessel approaches the limit of drift they permit. Usually, the vessel is set in motion by a change of wind or current, or by wave action. BUDOCKS (1962) recommends considering the horizontal force as one-third of the total wind force, acting in a direction parallel to the wind force, and considering the yawing moment as one-third of the yawing moment due to wind.

Forces on a moored vessel due to wave action are listed as being dependent on the following factors: (1) type of mooring (e.g., single- or multiple-cable moorings "in the stream," or moored "alongside" docks or dolphins); (2) ratio of wave length to ship length; (3) initial tension in the mooring lines; (4) ratio of depth of water to wave length; (5) ratio of draft to depth; (6) configuration of the ship; (7) height of fairleads above the dock; and (8) displacement of the vessel.

Though definitive solutions to the problem of wave forces on moored objects have not been developed, it is suggested that the following tentative equation may be used for rough approximation of forces.

(1) <u>Case I - Ship Moored "In the Stream" with Single Cable.</u>

$$R = 57\,A^2 B \sin^2 a$$

where R = steady average force in cable (lb)

A = one-half wave height (ft)

B = maximum beam of vessel (ft)

a = angle which the tangent at any point on the obstruction makes with the fore and aft axis. For a molded hull, use the average angle

Note: Maximum force on cable = 2R.

(2) <u>Case II - Ship Moored "In the Stream" with Cables Fore and Aft.</u>

Use a force four times that computed for Case I.

Another significant force factor for deep-ocean anchorage design is that of current on the connecting apparatus between the bottom and the moorpoint. Though at depths below 1,000 feet currents are believed to be less than 0.5 knot, even this velocity can result in large forces when applied to immense lengths of line and to possible numerous attachments on the line. Information on the calculation of forces due to drag is given in Appendix C, as it is applied in the design of a buoy anchorage system.

2-8. ANALYSES.

Anchorages achieved for large structures have generally used conventional anchors. These anchors are primarily designed to resist loads in a horizontal direction. Uplift loads such as occur in the anchorage systems under discussion seriously reduce the holding capacities of conventional anchors. Consequently, it becomes imperative that the load component at the anchor, when the implement is in position in a system, be horizontal or nearly horizontal under all conditions of loading. To accomplish this objective, sufficient scope is necessary in the leg of an anchorage system to span the distance from the anchor to the point of support (float or buoy) at the upper end of the leg without imparting uplift forces. A basic mooring leg of this type will "hang" in the shape of a catenary (Figure 2-1). Hydrospace Research Corporation, in its report on five deep-sea ship moors, presents a basic design approach used for these moors which appears in excerpted form in the following paragraphs (Hydrospace, 1964).

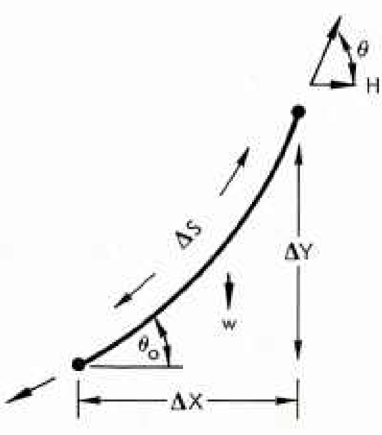
Any segment of the above mentioned catenary (Figure 2-1) may be described mathematically by the equations:

$$\Delta Y = \frac{H}{w}(\Delta \sec \theta),$$

$$\Delta S = \frac{H}{w}(\Delta \tan \theta), \text{ and}$$

$$\Delta X = \frac{H}{w} \ln \left[\frac{\tan\left(\frac{\pi}{4} + \frac{\theta}{2}\right)}{\tan\left(\frac{\pi}{4} + \frac{\theta_o}{2}\right)} \right]$$

This geometry is described in the following diagram, in which H is the horizontal component of the tension in the leg, and w is the weight per unit length of the segment.



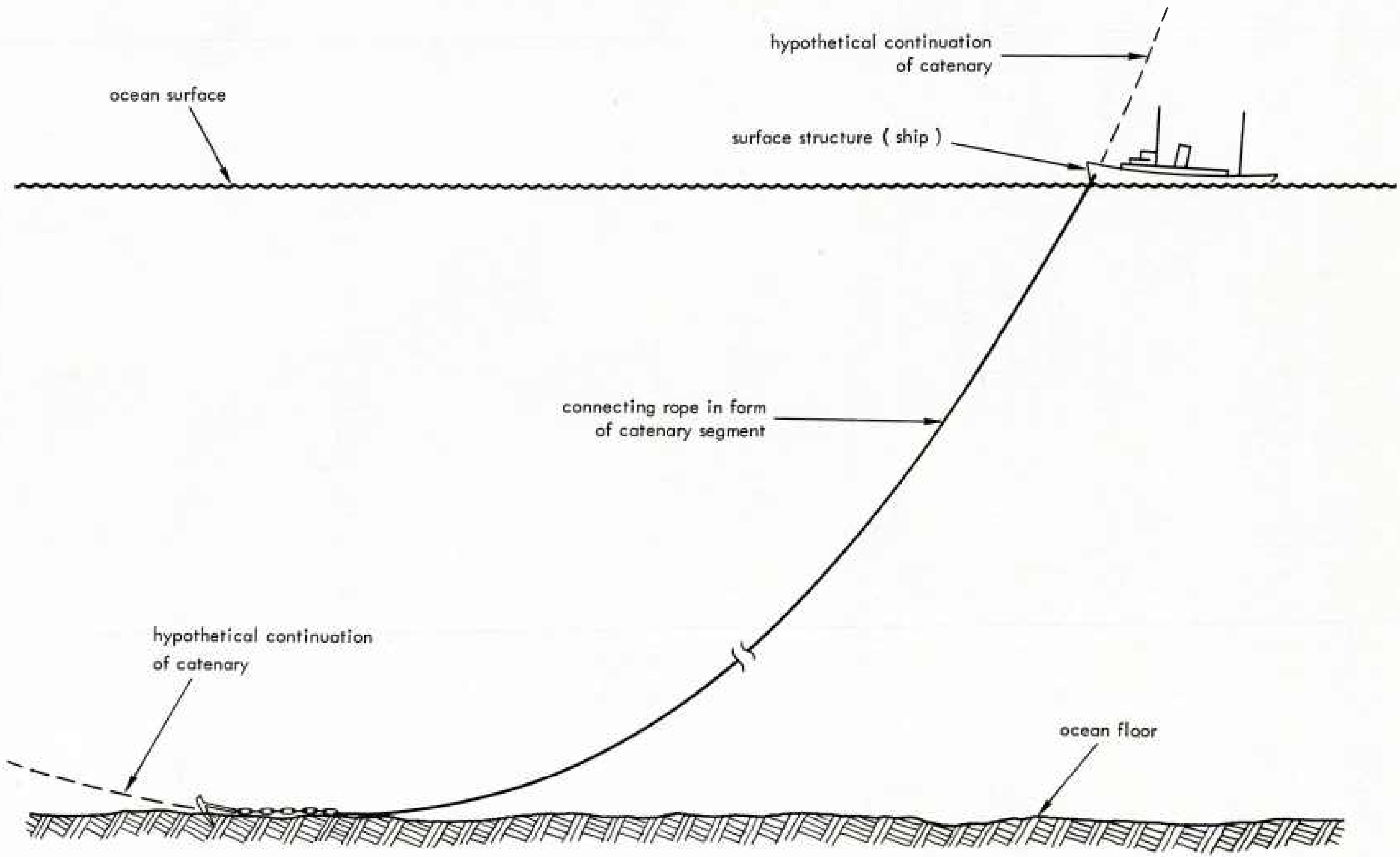


Figure 2-1. Mooring leg showing catenary form.

Expressed as above, or in any of the variations which have been optimized for particular applications, these relationships are sufficient to calculate the geometry and static tension in any mooring line, whether a simple, compound, or double catenary.

Primary technical considerations in the design of a basic mooring leg are therefore: (1) the maximum horizontal force to be applied, (2) the requirement that the anchor shank remain relatively parallel to the ocean bottom, and (3) the depth of water at anchorage site.

The primary criterion, of course, is the holding power of the leg, H; this parameter, representing the horizontal component of tension, is a constant throughout the catenary. Since the holding power per unit weight of a lightweight type (LWT) anchor is relatively high, this type is generally utilized as the basis for the leg. Selecting an LWT anchor to provide the necessary horizontal holding power, H, therefore becomes the first component specified.

To assure that the shank of the anchor remains horizontal, or nearly so, a heavy chain is normally attached to the anchor as the first portion of the scope of the leg. The length of this chain, S_c, and thus its total weight, $S_c w_c$, are therefore selected to provide the necessary mass to restrain the anchor shank. (In some cases a clump, or concentrated mass, is added at the upper end of the chain to reduce chain pickup by the overall tension in the leg.)

Since the length of the chain is known, calculation of its configuration begins by assuming an initial shank angle equal to the bottom slope, θ_0. Small anchor shank angles may be involved in certain cases, and $\theta_0 + \Delta\theta$ would then be the initial chain angle. For the specific length of chain, S_c, the angle at its upper end, θ_1, may be calculated from

$$\theta_1 = \tan^{-1}\left(\tan\theta_0 + \frac{S_c w_c}{H}\right),$$

wherein w_c is the weight per unit length of the chain in water. The vertical rise, ΔY_c, of the chain is then

$$\Delta Y_c = \frac{H}{w_c}\left(\sec\theta_1 - \sec\theta_0\right)$$

and the horizontal extension, ΔX_c, is

$$\Delta X_c = \frac{H}{w_c}\ln\left[\frac{\tan\left(\frac{\pi}{4} + \frac{\theta_1}{2}\right)}{\tan\left(\frac{\pi}{4} + \frac{\theta_0}{2}\right)}\right]$$

Wire rope is the usual component used in the remainder of the leg. Since the length of the wire-rope section of the leg is unknown, calculation to determine its shape must include the remaining depth of water to be traversed as the controlling parameter. Thus

$$\Delta Y_{wr} = D - \Delta Y_c$$

where D is the depth of the water at the anchor position. The angle at the buoy or moored structure is then determined by

$$\theta_b = \left(\sec^{-1} \sec \theta_1 + \frac{\Delta Y_{wr} w_{wr}}{H}\right)$$

The total scope of the wire rope may then be calculated from

$$S_{wr} = \frac{H}{w_{wr}} \left(\tan \theta_b - \tan \theta_1\right)$$

and the following equation will define the horizontal extension:

$$X_{wr} = \frac{H}{w_{wr}} \ln \left[\frac{\tan\left(\frac{\pi}{4} + \frac{\theta_b}{2}\right)}{\tan\left(\frac{\pi}{4} + \frac{\theta_1}{2}\right)}\right]$$

When a clump is included at the juncture of the chain and the wire rope, the calculation of the configuration of the wire rope is modified by the substitution of θ_1' for θ_1, in which case:

$$\theta_1' = \tan^{-1} \left(\theta_1 + \frac{W}{H}\right)$$

where W is the weight of the clump in water.

Hydrospace further states that the design equations outlined above are basic in nature, and must be augmented by considerable judgment in regard to dynamic variations of H, the problems encountered with sloping and irregular bottoms, means for providing adequate supporting buoyancy, and similar related factors. In no sense, therefore, in the opinion of these designers, is it possible to reduce the design of a deep sea moor to an exact science at this time.

The analysis factors summarized in the foregoing comprise the starting point in solving basic problems relating to the long catenary legs necessary for deep ocean anchorages until such times as anchors capable of resisting uplift forces become available. In addition to the Hydrospace report, several other exhaustive studies of the catenary problems have been made and published. They are listed in Appendix E.

2-9. BUOY ANCHORAGE DESIGN.

Sufficient experience has been gained in anchoring buoys in deep water to warrant considering them separately. Factors influencing the design of buoy anchorage systems include:

1. Forces on the surface float. These are due primarily to wind, wave, and current action, separate or concurrent.

2. Forces on the submerged apparatus including all submerged floats and all attachments. These are due primarily to subsurface currents. A vertical profile of the currents must be estimated until reasonable means for obtaining direct measurements is possible.

3. Size, shape, and displacement of the submerged and surface buoys. These characteristics are important in determining the amount of drag on the system and the amount of weight that can be supported.

4. Weight of the submerged gear. This indicates the amount of buoyancy required to support the system and influence the configuration of the connecting apparatus.

5. Angle of the cable at the surface or subsurface buoy and at the anchor. This indicates the amount of excursion that might be expected in single-riser buoy systems, and the horizontal and vertical force components at the anchor.

In applying the above factors, it should be remembered that the degree of refinement of analysis justified in a design for any given situation is dependent upon the amount and reliability of the information used in computations. An example of an analysis for a buoy anchorage system is given in Appendix C.

2-10. MISCELLANEOUS CONSIDERATIONS.

A variety of unique and special factors can be important in the design of anchorages in deep water. These include the effect of environment on materials, equipment, and operations; the legal aspects of placing constructions in deep ocean areas; and the protection and safeguarding of such constructions both during and after installation.

2-11. Chemical and Physical Conditions.

Conclusive information as to the deteriorating effect of the deep environment on materials for constructing anchorages is limited. Some researchers believe that in regions near the bottom both biological fouling and types and rate of corrosion will vary according to the nature of the sediments (and/or rock outcroppings) encountered at a particular site. Likewise at intermediate and near-surface levels, deleterious effects may vary with the character, composition, and quality of the ambient water as affected by currents, climatic conditions, and other natural phenomena. Pending acquisition of more firm knowledge of deleterious effects, a reasonable course is to select materials known to be resistant to deterioration under more familiar conditions.

Evidence is accumulating, however, on effects of the deep environment on materials. For example, recent U.S. Naval Civil Engineering Laboratory (NCEL) tests at the Pacific Deep Ocean Test Site, near Port Hueneme, California, indicate that chloride and magnesium ions apparently common throughout the ocean waters have definite deleterious effects on metals, though specific effects of these ions in specific metals are not yet determined. Reinhart (1964) reports aluminum alloys were considerably less affected by corrosion after four months' exposure at about 5,600 feet than would normally be expected at the surface, and that new-titanium alloys and steels containing titanium showed no corrosive effects at all under the same exposure conditions. In general, alloys exposed in these tests were less susceptible to stress corrosion cracking than at sea level. From these reports, then, it is reasonable to believe that some materials will be more resistant in the sea than under conditions above the surface. Experience with other materials is also proving valuable. In general, deterioration of cordage lines such as polypropylene and nylon has been minor in the installations in which they have been used.

2-12. Marine Life.

Most marine cables are fouled by the growth of organisms that collect along submerged lengths. When thousands of feet of cable are submerged, increased weight caused by fouling can result in unnecessary strain, even failure. It is not fully known to what extent marine life affects constructions at different depths and locations. Results of tests at NCEL provide helpful data. Part of this information was obtained from specimens on a Submersible Test Unit (STU) submerged 4 months on the ocean floor at a depth of 5,640 feet. The STU was retrieved in February 1964 and returned to the Laboratory for tests and analyses. Muraoka (1964a) reports that the relative deteriorating effects of deep-ocean micro-organisms on plastic in rubber electrical insulating materials show: (1) neoprene is highly susceptible to microbial deterioration, yet highly resistant to water absorption in the absence of microbial activity; (2) polyethylene is strongly resistant to microbial deterioration, but after 14 months' exposure it becomes highly susceptible to water absorption; (3) silicone rubber, GR-S rubber, and polyvinyl chloride (PVC) are all fairly resistant to microbial deterioration and to water absorption.

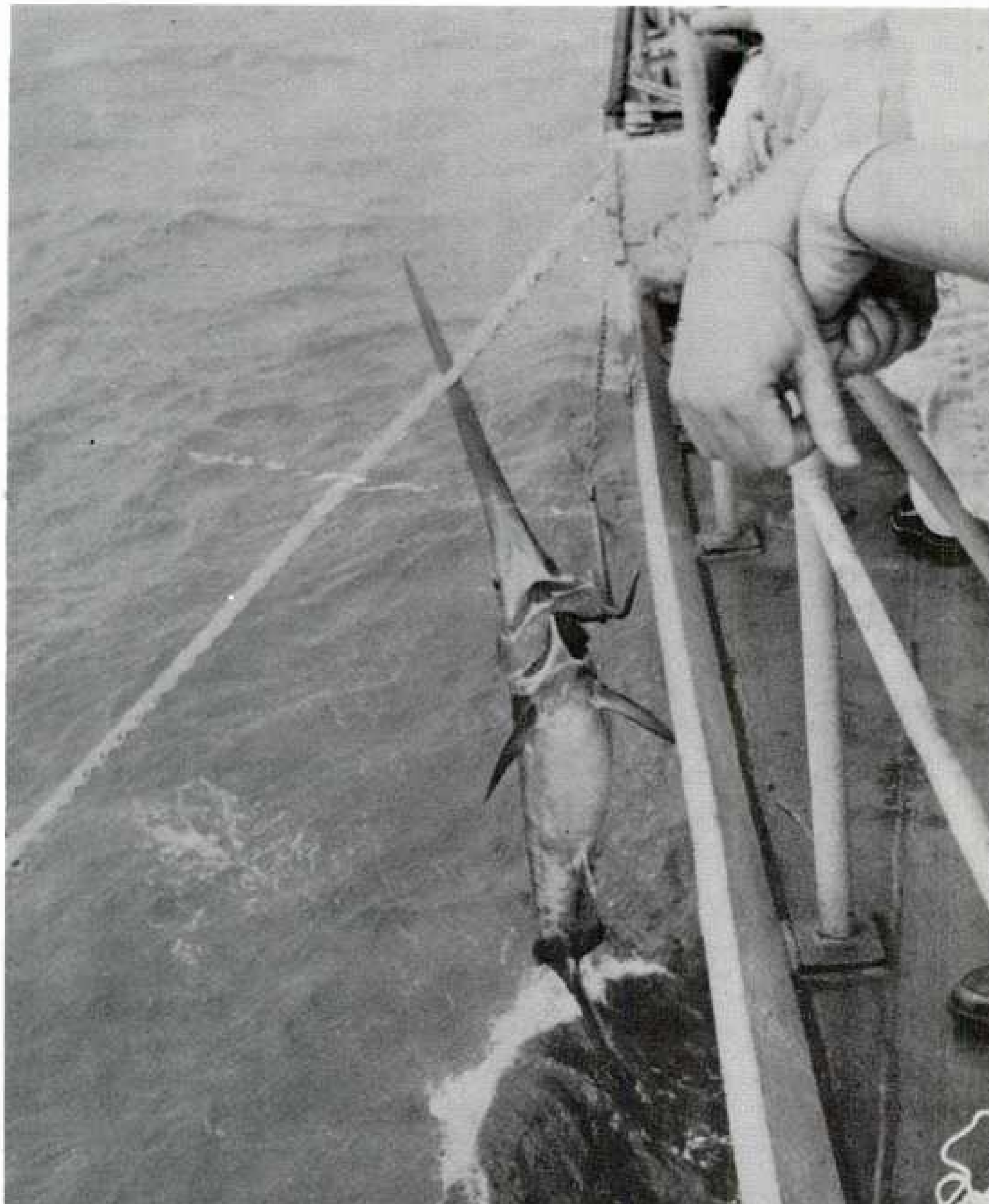
The knowledge obtained about the behavior of various insulating materials in this Laboratory study could be applied to practical use. For example, a superior electrical cable for long-term application in the marine environment could be developed by covering neoprene rubber, which is resistant to water absorption in the absence of micro-organisms, with polyethylene which is resistant to microbial deterioration. Muraoka (1964b) further reports that there were no marine-fouling organisms attached to the metal test specimens in the STU. Some of the plastic materials were covered with a bacterial slime growth, as were nickel-plated shackles. Cotton and hemp rope and burlap wrappings showed degradation by microbial activity. Pine test panels and manila rope were attacked by marine boring organisms. Various species of fouling organisms were found on rock samples collected from the ocean floor in the vicinity of the STU test site.

Turner (1961) reports a wooden panel hung at a depth of 9,000 feet was heavily attacked by teredo ship worms. Also, this marine borer has attacked nylon cordage in deep water and has been found in the lead sheathing of submarine electrical cables at 18,000 feet (International Oceanographer Foundation, 1963).

Evidence is accumulating on contacts and damage to lines and cables by large marine creatures such as whales, sharks, squid, and swordfish. A parted polypropylene line attributed to giant squid is reported by Turner (1963). A swordfish has been trapped with its bill wedged between the strands of a polypropylene rope at a depth of 1,000 feet (Figure 2-2).

Whales have become entangled in and damaged communication cables at depths to 3,500 feet (Heezen, 1957). Sharks sometimes strike or bite at any object that attracts their attention. A small float on a line, a tag end of a line, or tape on an instrument cable is frequently bitten off or damaged by sharks in buoy anchorage systems.

The effect of marine life on anchorage systems needs to be taken into account in design. Every anchorage component should appear continuous with the system in order to minimize shark bite. Tags, pigtails, and small floats of colors different from that of the line should be avoided. Black mooring lines appear to be less susceptible to attacks by marine life than white. Therefore, black line is considered advantageous for use in most systems using cordage types of line. Steel cables are believed less susceptible to damage by marine life than the synthetic lines.



A 300-lb swordfish is hopelessly snagged in the braids of a line suspended from the research ship MISSION CAPISTRANO.

Figure 2-2. Example of fouling of anchorage system lines by large marine creatures.

2-13. Operating Limit of Seas.

The critical limit of operating seas can be a vital factor in design as it relates to construction of the anchorage. For the major complex anchorage systems yet achieved, near-ideal sea and weather conditions were required, as in the case of TOTO II (paragraph 4-11). This remains the case for other like or comparable systems, and obviously represents a major problem. When the amount of equipment, material, supplies, and personnel involved in such an operation and the logistics coordination required are considered, the necessity of raising the critical limit of operating seas is evident.

Another example relating the operating limit of seas to construction operations is that of driving piling under adverse conditions. It is reported (NCEL, 1964) that 24-inch-OD piling was installed off San Clemente Island during 60 mph winds and 12-foot, 8- to 10-second waves. Usually the critical limit of installing piling is determined by either heave of the surface vessel or excessive lateral surge or sway. Many factors such as size of the surface vessel, type of seas, currents, and mooring systems to be installed, affect this limit. Generally, heave in excess of 10 percent of water depth constitutes the critical limit of operating seas for drilling operations. This is approximately equivalent to Navy Sea State Six.

2-14. Legal Requirements.

The installation of a deep-ocean anchorage system necessitates obtaining required permits from the responsible authorities (Daubin, 1964a). Coast Guard and other agencies concerned must be satisfied as to design, location of proposed anchorage, periods of inspection and expected extent of time in place, possible hazards to navigation, nature and extent of markings. They must also be satisfied as to what recovery procedures are contemplated in the event the surface buoy parts from the anchorage system and thereby becomes a free-floating menace to navigation. If radio signals are to emanate from the system, the wave length and strength of signal must conform to rules of the agency controlling them. Electrical or gas equipment must be installed in such a way as to protect an investigating public from injury. Recent recommendations of the Inter-Governmental Oceanographic Commission (IOC) and action by member nations should be considered. Further information on these recommendations is given in Appendix B. The buoy system must, in other words, conform to the different requirements of various controlling agencies.

2-15. Interference from Outsiders.

Pilferage and willful damage occur increasingly as greater ocean use by the public brings more people in contact with buoys. Boat-shaped buoys are attractive for theft. All types of buoys appear to be alluring targets for people with firearms.

In addition to hazards created by increased public use of the ocean, passing ships often attempt to recover deep ocean buoys in the belief they are salvageable items. Valuable gear and instruments have thus been lost.

A possible remedy for both types of interference from outsiders is to construct buoys so that they will attract little attention. Another remedy worthy of consideration for particularly expensive and valuable buoys located in the reasonable range of military airplanes or other patrol craft, is to attach an alarm device which will send a signal when the buoy is boarded or damaged. Apprehension of a few trespassers could act as an effective deterrent. A third remedial measure is to construct surface buoys with compartmented and/or foam-filled flotation sections as a protection against sinking.

PART 3
HARDWARE

3-1. GENERAL.

Much hardware for deep ocean use is in the experimental and developmental stages. Many requirements have not yet been adequately met. In general, standard anchors, tackle, and gear are being modified or otherwise adapted to deep water use. Other items such as piles offer potentials that are being explored. This part deals with current practice in the use of bottom implements, connecting apparatus, accessories, and materials.

3-2. BOTTOM IMPLEMENTS.

The term "bottom implement" here includes the components of an anchorage system that rest on, or are embedded in, the ocean bottom to provide the securing force to a construction or mooring. Size, location, purpose, and degree of fixity of these installations dictate the amount and direction of forces - bearing, uplift, lateral, or combinations thereof - that bottom implements must withstand. The selection of the implement is dictated not only by these forces, but also by expediency based on what is available and can be placed.

Many types of anchors exist that fulfill some of the functions of a bottom implement. But the bottom implement may also be a pile, footing, or any other construction feature, or combination of features, that accomplishes the purpose of the anchorage. Some of these have been used in deep ocean anchorages while others have found use only in shallow water.

3-3. Conventional Anchors.

Conventional anchors (Figure 3-1) have been adapted wherever possible to meet deep-ocean anchorage needs. They are readily available, as are data on their performance characteristics based on the history of their use in harbors and other shallow water locations. They may be classified as deadweight and standard.

3-4. Deadweight. Deadweights, also referred to as clumps, masses, and sinkers, are the simplest of conventional anchors. They have served most commonly for small buoy installations. The two materials used most often for deadweight anchors are concrete and steel. Concrete has been cast into various shapes, from truncated pyramidal cones to flat rectangular blocks with holes. Steel has been used in solid blocks and in elementary constructions such as cross-welded lengths of scrap railroad rails.

Deadweight anchors are inexpensive and expendable and fairly easy to place, since they may be readily dropped overboard and require no preset pull to obtain holding power. Their prime capability is that of resisting uplift forces by means of their own deadweight in water. However, their efficiency is low. They are susceptible to lateral displacement under relatively small lateral loads, especially if these are coincident with uplift loads. Their reliability is further reduced on sloping unstable bottoms, where they may slide or roll. Consequently, deadweight anchors are used only as a matter of expediency and in minor installations. Sizes and weights are large in relation to their holding capacities, and handling, transporting, and placing them becomes increasingly difficult with size. Consequently, the practical limit of their holding power against horizontal displacement is in the range of 3,000 to 7,000 pounds, which would require minimum weights in water of 4,000 to 8,000 pounds, respectively.

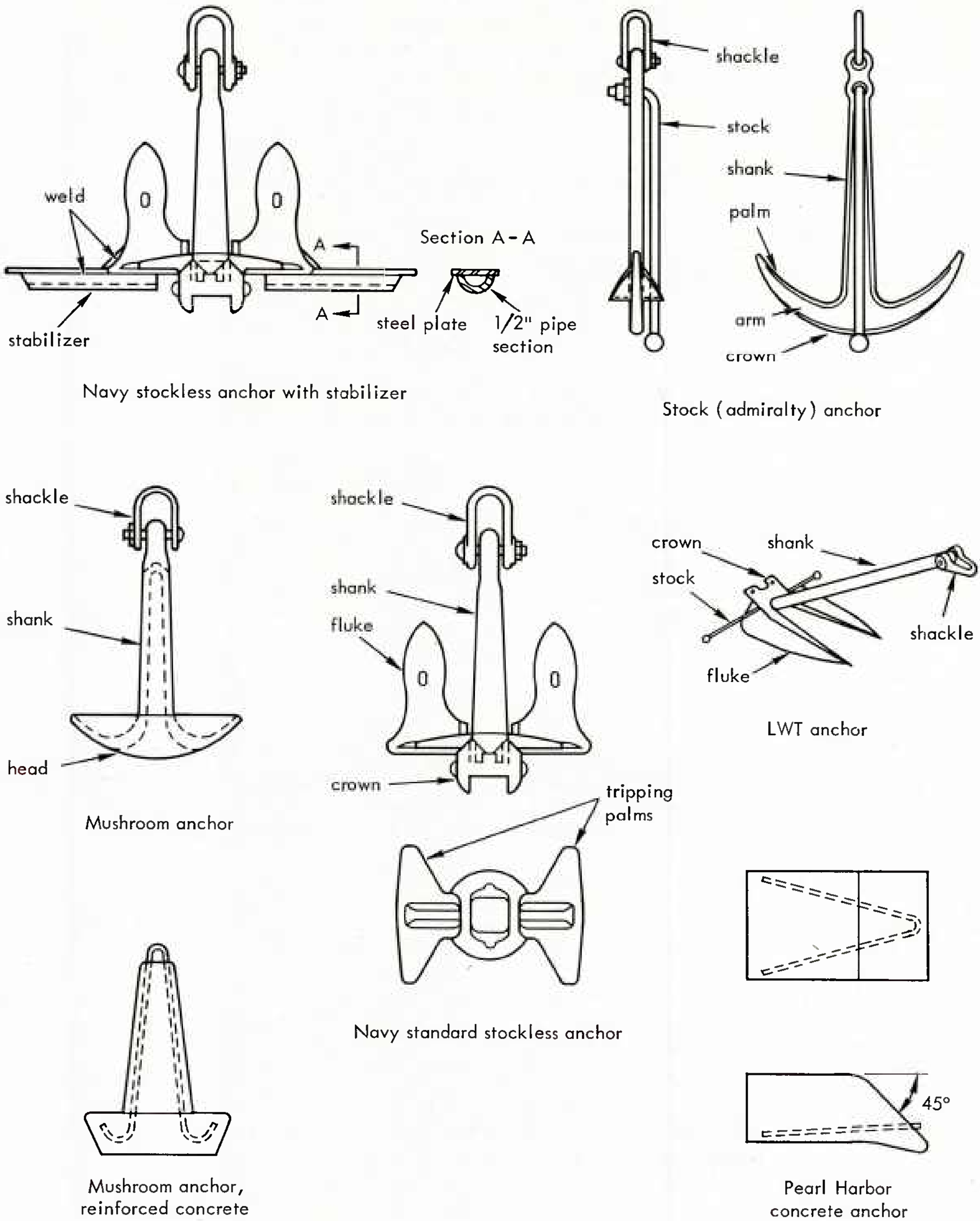


Figure 3-1. Conventional anchors with principal parts indicated.

3-5. Standard. Standard anchors are those evolved to present form from types used down through the centuries to secure ships, barges, and other floating structures in position in harbors and other shallow waters. Typically, such anchors depend upon their embedment in the bottom to obtain holding power. They achieve embedment by being pulled along the bottom by a horizontal force, and their prime resistance capability is against continued horizontal loads applied in the same direction as the setting force. Uplift forces tend to extract the anchors and lessen their holding power. Horizontal forces applied in directions other than the original setting forces also reduce holding power, and result in considerable displacement of the anchor before the maximum power is again attained.

Anchors used by the U. S. Navy are representative of standard anchor designs. Six of these designs, a lightweight (LWT), a mushroom, a mushroom of reinforced concrete, a Pearl Harbor concrete anchor, an Admiralty anchor, and the Navy stockless anchor, both the standard and the model with stabilizer, are shown in Figure 3-1, which illustrates major parts, types of construction, and principles of operation. The development of another design, the all-weldment (STATO) anchor for use in sand and mud bottoms, is described by Towne and Stalcup (1961). Also presented in their report are discussions of the tests and results, suggestions on proof-loading techniques, and a statistical approach to predicting holding powers. A family of STATO anchor sizes ranging from 200 to 15,000 pounds is shown in Figure 3-2.

A measure of anchor performance is its holding-power-to-weight ratio. The approximate holding-power-to-weight ratios of four types of conventional anchors are tabulated below.

Approximate Anchor Holding Power to Weight Ratios

Anchor	Sand Bottom	Mud Bottom
Concrete	3-1	1-1/2-1
Baldt (stockless)	6-1	2-1
LWT - Lightweight (stock)	16-1	9-1
STATO (stock)	20-1	15-1

Opening angle between fluke and shank is of prime importance in effecting rapid and deep embedment of anchors for good holding power performance. The optimum angles are about 35 degrees for sand and 50 degrees for mud bottoms (Towne and Stalcup, 1961). The STATO anchor incorporates a wedge insert in its design that makes it suitable for both types of bottom, use of the wedge changing the optimum, set angle for mud to that for sand (Figure 3-3).

Standard anchors in general can be constructed of steel, concrete, or reinforced concrete. Generally they have two major parts, a shank through which the load is applied, and a configuration area constructed to encourage embedment and present a surface to bear against the soil for development of holding power. The configuration can be in the form of palms, flukes, or a mushroomlike entrapment area. Concrete anchors are so cast that one face is sloped and thus tends to embed the whole anchor as it is dragged on the bottom.

Other parts of conventional anchors shown in Figure 3-1 are designed to facilitate their functioning and enhance their capabilities. The crown on the LWT anchor serves to trip the flukes and cause them to embed faster and deeper. The stock acts as a stabilizer to prevent the anchor from rotating, which causes loss of holding power. Specific criteria on sizes, weights, and performance characteristics of these conventional anchors as normally used in shallow waters can be obtained in standard reference publications such as the BUDOCKS design manual (BUDOCKS, 1962).

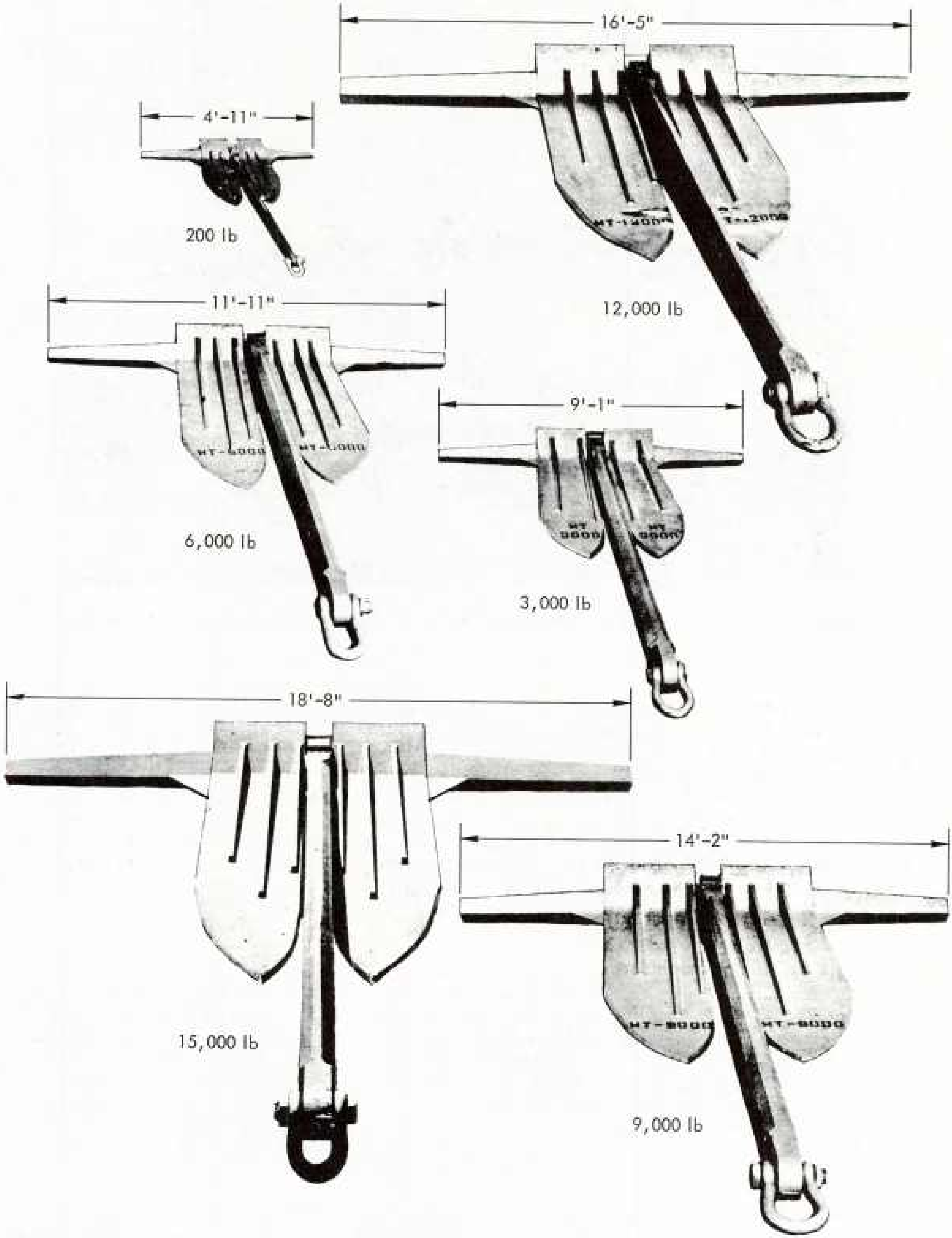


Figure 3-2. Family of sizes of STATO anchors.

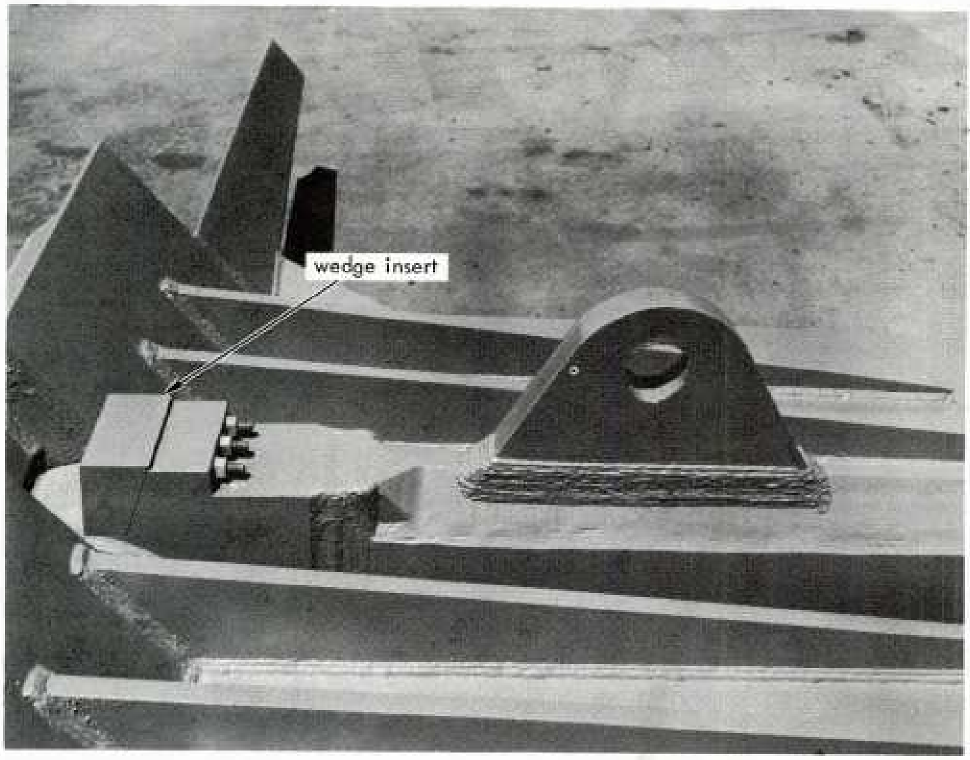


Figure 3-3. STATO anchor with wedge insert to assure proper fluke angle for sand.

Conventional anchors, designed to resist horizontal forces, have been used in both single-riser and multileg deep-ocean anchorage systems despite the fact that vertical force components are major considerations in both cases. Because their characteristics are known for normal use, some approximate calculations of holding powers can be made for deep sea application. Also, the conventional anchors are available in a variety of sizes. Nevertheless, some means has been considered necessary to attempt to compensate for the vertical force components introduced by use of the anchors in deep water. For the single-riser-line anchorage systems, for example, an arrangement of two anchors in tandem connected by heavy chain has been improvised (Huntly, 1963). Again, heavy deadweights have been placed in the line adjacent to the anchor so that the pull on the anchor will be horizontal, or nearly so.

3-6. Explosive Anchors.

A major consideration in the construction of many deep ocean anchorages is the development of bottom implements that can be rapidly, economically, and accurately placed, and that will provide great resistance to uplift forces and thus help reduce the amount of connecting gear. One approach to such development is represented by explosive anchors. The term "explosive" refers to the propelling force by which the anchor is embedded in the bottom. Explosive anchors of 5,000 to 300,000 pounds' capacity have been built and placed with varying success in depths of 200 feet in bottoms ranging from sand to shale and coral. Anchors in the range of 5,000 to 25,000 pounds' capacity appear to be reasonably well perfected. The higher capacity anchors are still in the experimental stage of development.

The principle of operation of an explosive anchor is similar to the action and reaction of a projectile and cannon. The explosive charges contained in a cartridge-type cylinder propel the anchor (projectile) into the bottom by reacting against a cone-shaped metal mass (cannon).

As the anchor embeds itself in the bottom, flaked cables or straps unfasten and trail behind. These straps or cables are the means by which the attachment to the embedded anchor is made. As load is applied to the anchor it assumes the attitude of greatest resistance to pullout.

At present, two basic designs of explosive anchors are operational. One type employs movable flukes that open outward umbrella fashion when the anchor moves upward under load (Figure 3-4; also chapter 3, Figure 3-6). As the flukes open, resistance to pullout increases until they are in the fully open position. The second type (Figure 3-5) utilizes its shieldlike shape to attain holding power. It is propelled into the bottom endwise, thus presenting minimum resistance to penetration. When the shield-type explosive anchor moves upward under applied load it is keyed, by hinged flaps and eccentric load-attachment point, over to a position presenting a broad surface area to the soil or other surrounding material.

The fluked anchor is adaptable to different bottom conditions by changing the shape and number of flukes. For example, larger and more numerous flukes would be used in a soft bottom condition than in a firm or coral bottom. One other feature of the fluked anchor that is under development, but not yet perfected, is a modification for use in a rock or other hard-cemented-type bottom condition. This modification is an additional projectile attached to the main anchor and extending below it. The projectile is in the form of a spike and does not have flukes. It would embed itself in the hard bottom and remain fixed by virtue of the character of the bottom. The shield-type explosive anchor is not alterable for different bottom conditions, but developers believe it to be functionable in a wide variety of conditions.

In soft mud bottoms the lack of resistance of the soil to penetration by the anchor may permit an explosive anchor to travel beyond the length of cables or straps by which it is attached to the riser lines of the mooring apparatus, and thus cause the cables or straps to break. This negative result occurred in tests of explosive anchor designs in San Francisco Bay mud bottom (Thomason, 1964).

Experience in placing explosive anchors at depths greater than 200 feet is limited. However, in at least two instances it is claimed that explosive anchors have been successfully implanted in very deep water. Eight 50-kip rated capacity explosive anchors were triggered at a 10, 000-foot depth in 1960 in the Atlantic off the coast of Bermuda (Thomason, 1964). Single-riser taut-line buoys were attached to these anchors. In the second case, three 5-kip rated capacity explosive anchors were placed in about 6, 000 feet of water at the equator near the southern end of the Pacific Missile Range. The three anchors were used to hold one single-riser taut-line buoy. The explosive anchors in both the 10, 000- and 6, 000-foot depths were triggered at the surface by an electric impulse through a wire attached to the mooring line. It is believed that achieving the necessary reliability of operation and placement of explosive type anchors in deep ocean areas depends primarily upon adapting the fuse mechanism to function properly at great depths, and by improving the seals for the powder cylinder containing the explosive charge. For incorporation into deep water systems, the anchors should be capable of firing on contact with the bottom instead of having to be actuated from the surface. The explosive charge must be kept dry and not subjected to excessive pressures prior to discharge. These improvements appear to be attainable. The amount of additional explosive charge required to offset the increase in ambient pressure is negligible.

The potential offered by explosive anchors used as bottom implements is evident in high holding-power-to-weight ratios that approach 500 to 1 against uplift. Thus a 300-kip capacity anchor would weigh about 600 pounds, and provide holding capacity in the direction most effective for permitting reduction in the amount of gear and apparatus required for completing an anchorage system in deep water.

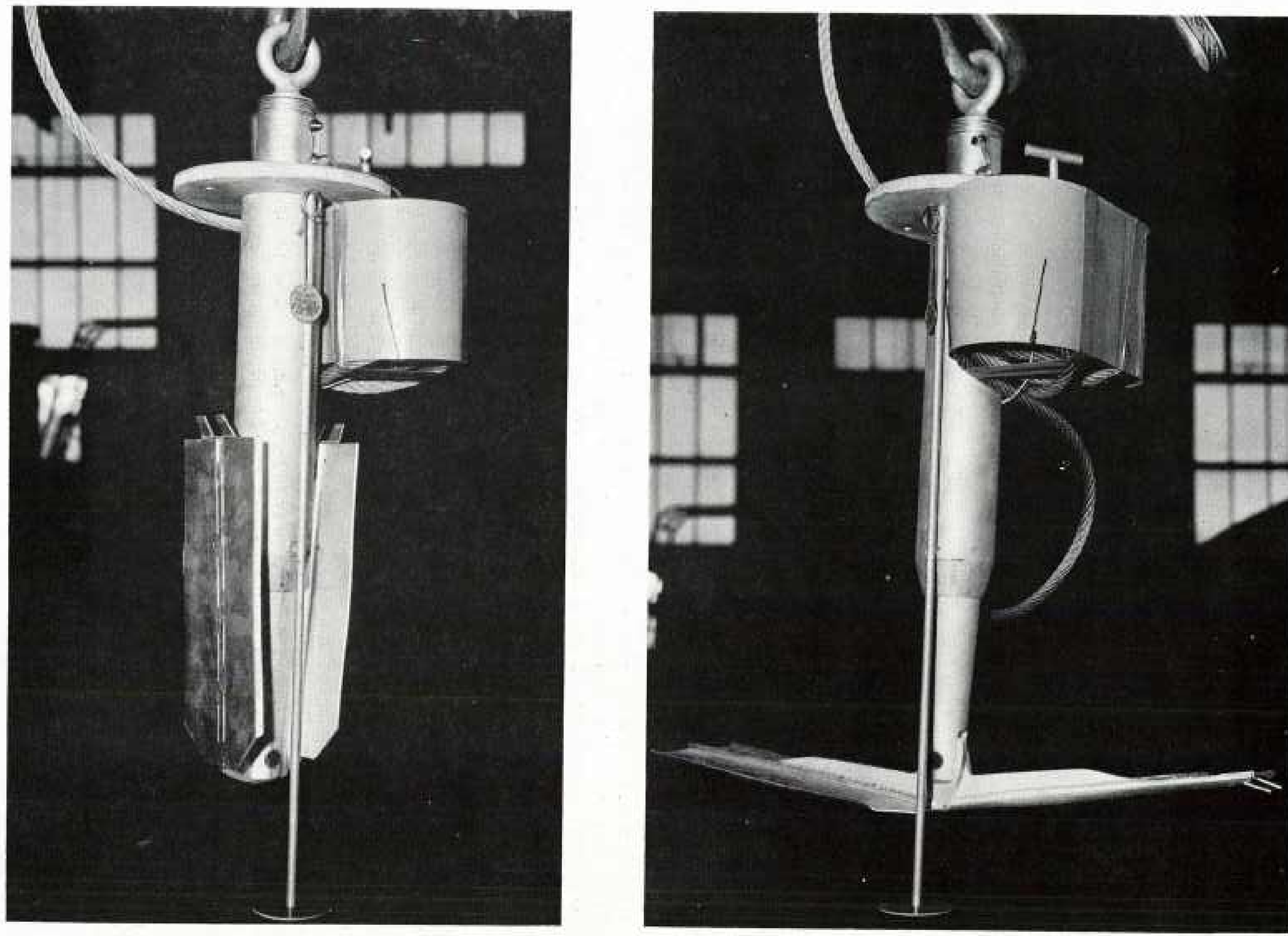


Figure 3-4. Explosive type of anchor with opening flukes.

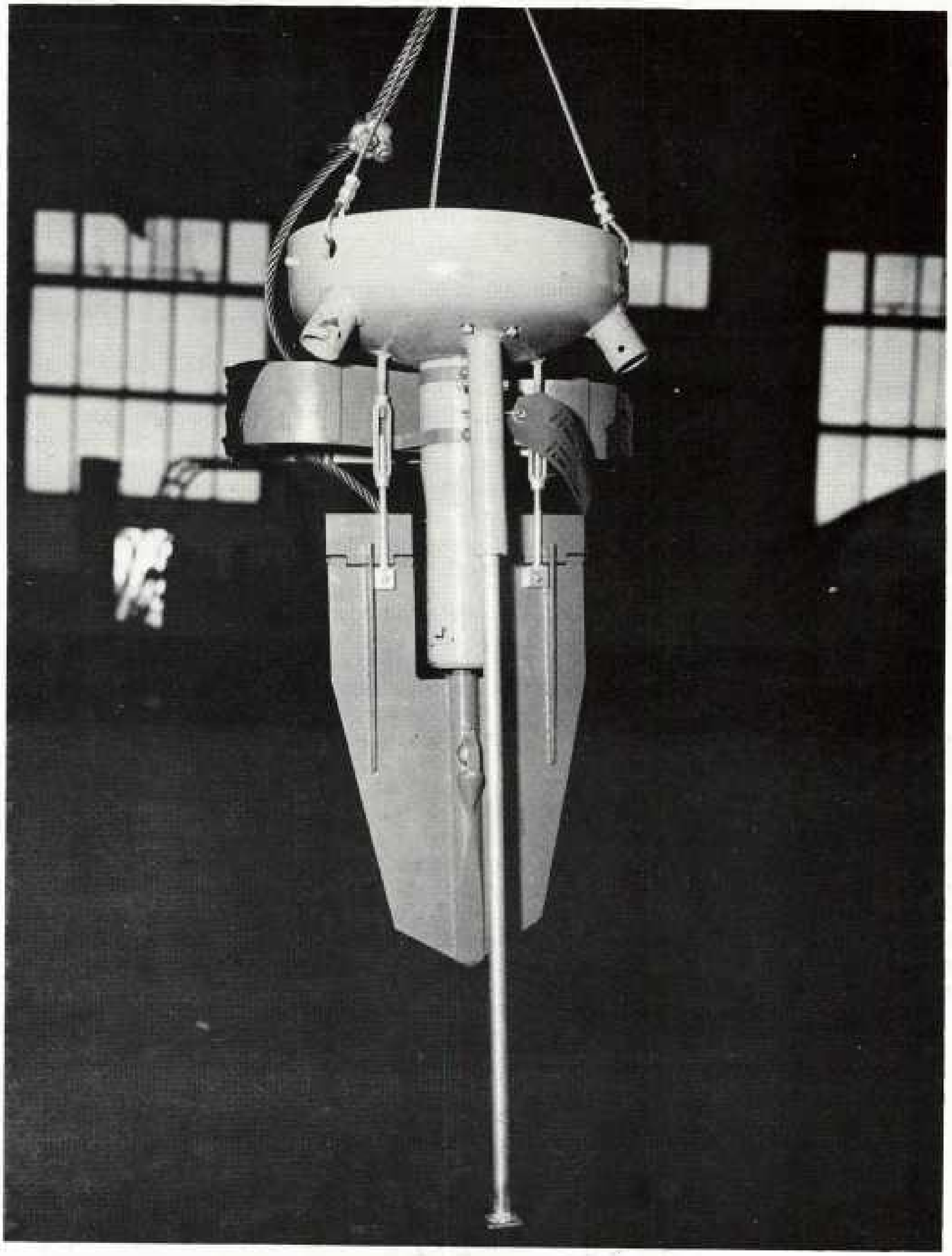


Figure 3-5. Explosive type of anchor with shieldlike shape.

3-7. Piles.

Piles perhaps could provide the greatest potential in the near future for meeting the various requirements of bottom implements were it not for the time and expense involved in their placement. They can develop high capacity to resist bearing, uplift, and lateral forces from any direction. Conceivably, they can be made large enough and embedded firmly enough to withstand any forces induced by contemplated structures. Another advantage is that they attain their maximum capacity without appreciable movement.

Piles are emplaced by drilling or driving or by a combination of the two methods. Once the pile is in place, grouting may be pumped into and around it both to strengthen the pile against bending and to increase its resistance to pullout or settlement under applied loads by fusing it to the surrounding bottom material. Drilling, driving, and grouting are discussed in part 6.

Currently, piles have been placed in depths to 400 feet on numerous occasions for use in anchorage systems for floating oil-exploration rigs. Plans are underway in at least one location to implant them in 1,000 feet of water. It is believed that piles can be placed in depths wherever drilling can be accomplished within the depth limits of an operable television system. A number of designs are in use or being considered. These vary depending upon intended method of placement and type and amount of anticipated load. Construction can be of steel or reinforced concrete. Wooden piles are not believed practicable because they are susceptible to biological attack and deteriorate in short time. There is evidence of attack on wood at depths to 9,000 feet (Turner, 1961), and evidence indicates that attack is likely at all depths. Though the useful life of wooden piles in shallow water can be extended to a period of years by treatment with creosote and/or with certain other compounds, the effectiveness of such treatments at great depths can as yet only be surmised.

Of the standard steel-pile shapes, such as, H, MZ, MP, and round commonly used for piles in land and in shallow-water constructions, the round shape is most practicable for deep ocean anchorages since it is adaptable to the drilling or driving method of emplacement, has high structural strength to resist bending equally in any direction, and presents a shape at its top that can readily receive various types of connections including rotatable ones (Figure 3-6). The other steel shapes are difficult or impossible to drill into place in deep water, and also present a weak and a strong axis against bending.

One proprietary conceptual design (Dames, 1963) that resists exceptionally high uplift and sidewise forces is shown in Figure 3-7. This pile consists of a long section of rigid material that is embedded to 600 feet into the ocean floor and a shorter section of semiflexible material at its upper end that bends in the direction of applied force. The lower section is grouted to fuse with the surrounding bottom material. The flexibility of the upper section allows primarily tension forces to act only through the length of pile. This pile has been tested in shallow water in San Francisco Bay. Its eventual use in deep water depends upon operation placement factors.

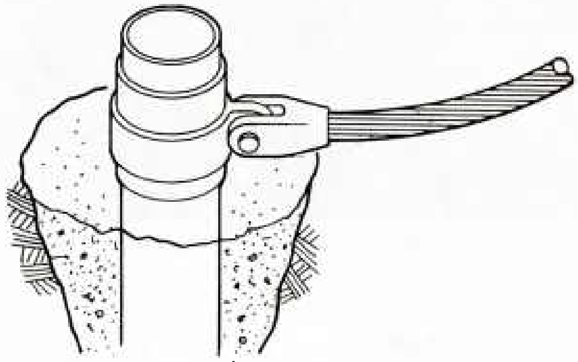


Figure 3-6. Drilled and grouted pile anchor with rotatable head connection.

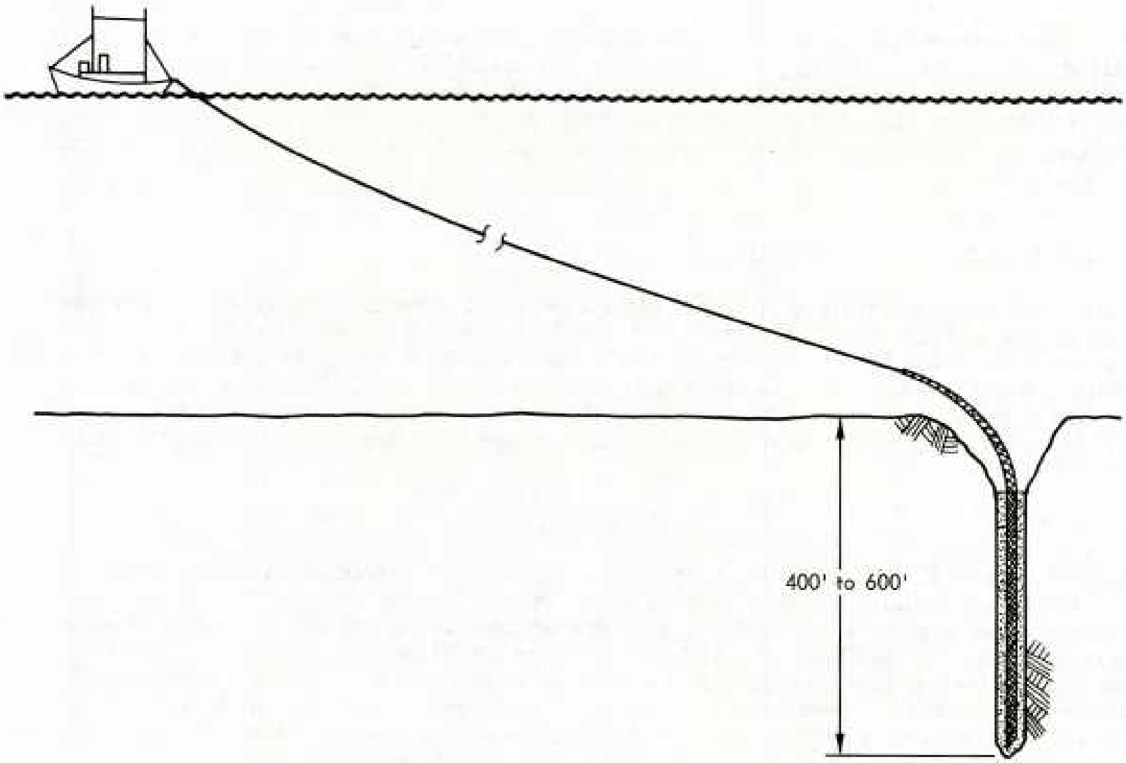


Figure 3-7. Part-rigid, part-flexible pile anchor.

It is reported that Global Marine Exploration Company tests drilled-in piling at almost every drilling location and has yet to experience a single piling failure. Lateral mooring loads (in surge) of over 100,000 pounds are not uncommon in a normal anchor pile (13-3/4 inches OD). Piling has been tested by using large winches on surface barges and pulling one pile against another with winch loads as high as 100,000 pounds. Off San Clemente Island, 24-inch-OD piles were given a lateral test of 45,000 pounds without failure. A recent calculation of the lateral strength of a 30-inch pile in fairly hard-compacted sand indicated a lateral load of 160,000 pounds could be safely withstood.

3-8. Other Anchors.

Attempts have been made to counteract the uplift-force component on conventional anchors without use of weights or extra anchors. One such effort is represented by the Stimson anchor (Figure 3-8). It was developed by the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts (Richardson, 1963). A chain bridle is attached to the anchor so that its convex-curved surface is up, and the edge in the direction of the horizontal force component is lower than the trailing edge. Thus, the anchor tends to dig into the bottom when dragged in any direction. It achieves its holding power by its own weight plus the bottom soil resistance to its pullout. The Stimson anchor has been used with single-riser lines leading to small buoys. Its safe maximum capacity is about 4,000 pounds. The chief advantage over conventional anchors is that only one implement is required on the bottom, resulting in simplified placement procedures.

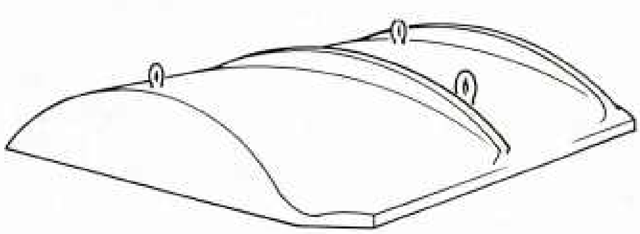
Still other anchor concepts and designs will probably be available in the future to help meet various placement and loading requirements. For example, development of such devices as anchors that will embed themselves by their free-fall impetus and anchors that have self-contained driving, drilling and grouting capabilities would permit more reliable economical designs, shorten and simplify placement procedures, and reduce the amount and complexity of the gear required.

3-9. CONNECTING APPARATUS.

Chains and ropes and their appropriate fittings provide connecting links between fixed bottom implements and structures being anchored. In deep ocean anchorages thus far accomplished, the use of chain has been limited to relatively short lengths at the upper and lower extremities of the apparatus. Such chain has generally been of standard type. The great intermediate portion of anchorage systems has been comprised of rope of various types. Fittings and connections have generally been standard types, though fabricated of corrosion-resistant materials.

3-10. Rope.

According to de Kerchove (1961), rope as used in maritime operations is defined as a construction of metallic wires or twisted hemp, manila, cotton, flax, or jute fibers, so intertwined as to form a thick cord capable of sustaining relatively severe strains (Figure 3-9). In considering what has been achieved in deep ocean anchorages, this definition must be expanded to include rope constructed of any of the various synthetic fibers. Both metallic and nonmetallic ropes have been used in a number of anchorages. Selection of the optimum type or combination of types is difficult because the extreme lengths involved cause stowage, handling, and weight problems. There are advantages and disadvantages for each type.



Anchoring Procedure:

1. Lowering position.
2. Nose chain slack - anchor begins to dig in.
3. Bridle comes taut, maintaining optimum angle of incidence.

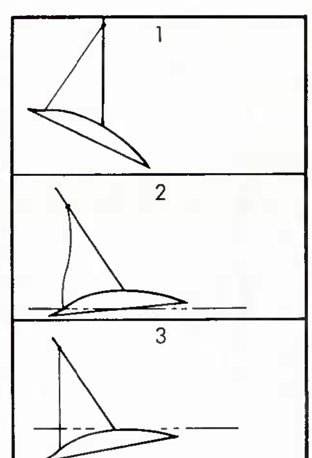
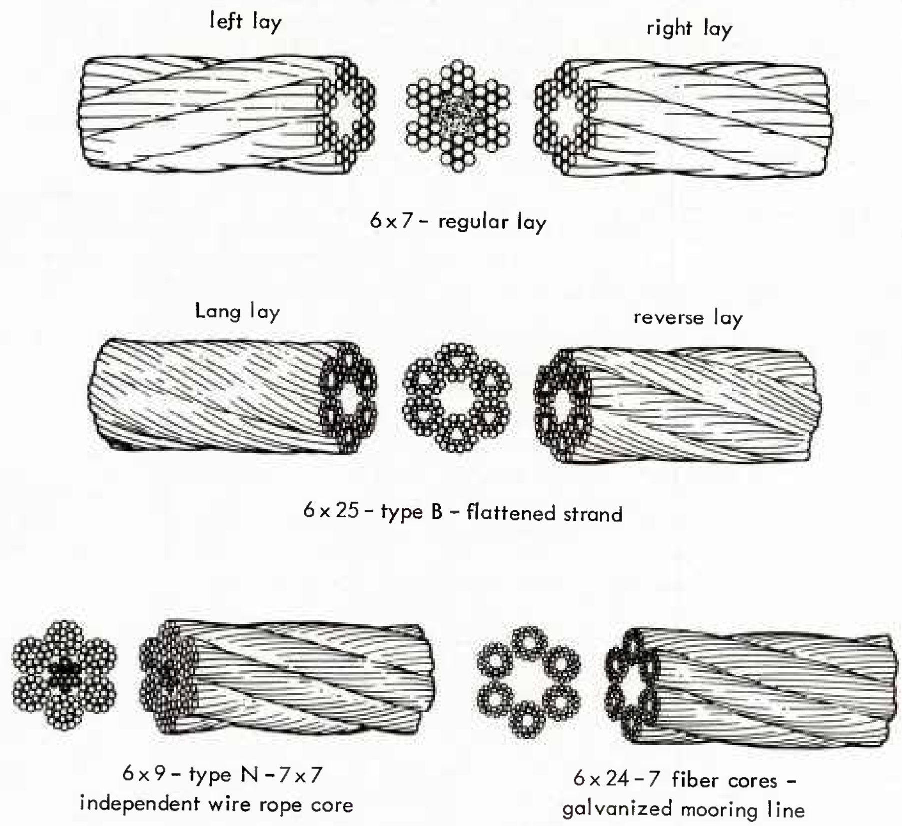
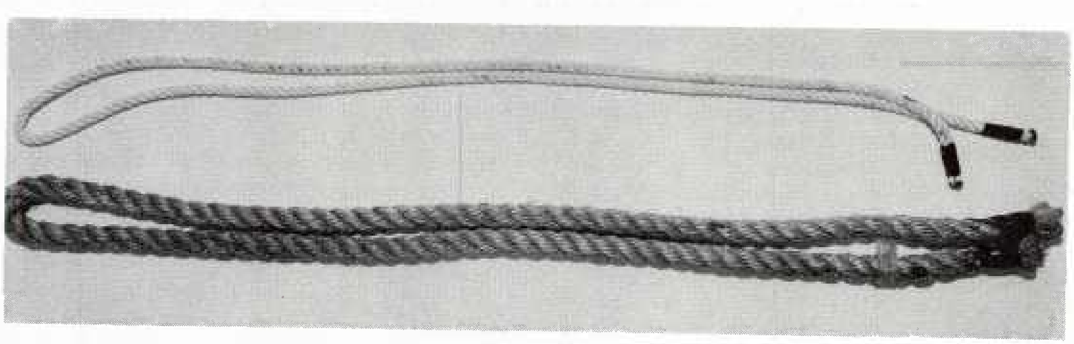


Figure 3-8. Stimson anchor - Modified drag type.



©Wire Rope Handbook for Western Wire Rope Users, United States Steel Corp.

(a) Wire rope



(b) Synthetic fiber ropes

Figure 3-9. Examples of basic rope construction.

The characteristics most sought in ropes are: (1) high tensile strength, (2) light weight, (3) nonbrittle qualities, (4) capacity for repeated bending, (5) abrasion and crush resistance, (6) kink resistance, (7) torque balance, (8) corrosion resistance, (9) ease in handling, (10) low cost, and (11) ease of splicing. The principal kinds of rope offering potential for deep ocean anchorages are metallic rope composed of extra-improved plow steel, improved plow steel, galvanized steel, stainless steel, bronze (90 percent copper, 10 percent zinc), and phosphor bronze; and nonmetallic rope of manila, nylon, dacron, polypropylene, polyethelene, and fiber-glass composition.

Metallic ropes have been used on the anchorages for larger structures, such as TOTO II (Hydrospace, 1964) and the anchoring of the USNS GIBBS (Beck, 1962). Nonmetallic ropes have been used in most anchorages for buoys, as in the NOMAD buoy installation. A few small buoys placed for a short term have employed single-strand fine wire in their moorings.

3-11. Metallic Ropes. As a group, the metallic ropes possess high tensile strength and are rugged and abrasion resistant. On the negative side, they are heavy, difficult to handle in the large quantities required, and cannot be fully torque-balanced without sacrifice of other desirable qualities such as abrasion resistance and strength.

The nonferrous metallic ropes like bronze and phosphor bronze are used in special applications where nonmagnetic properties are important. Their other chief advantage is their extremely high resistance to corrosion. This is of value, but the high cost of these ropes currently makes them impractical for use throughout a moor. Their application is thus limited to pendants, connecting lines, and lines supporting appurtenances or instruments.

Among the other metallic ropes, those made of steel wire are of primary interest. There are two chief considerations in the selection of steel wire ropes for use in deep ocean anchorages: (1) the composition of the metal in the individual strands, and (2) the construction of the rope from the strands. Both composition and construction are interrelated as they influence the characteristics of the rope. For example, the ability of a wire rope to withstand abrasions is partly determined by the size of the outer wires. The larger the outer wires, the better the rope is able to resist abrasion. However, the larger the outer wires, the less flexible is the rope. Smaller, more numerous wires contribute to flexibility but tend to make the rope less resistant to corrosion. Composition of the wire strands is also important in establishing particular qualities such as hardness, tensile strength, and flexibility.

There are many compositions and constructions of wire ropes. These are discussed in detail in the wire rope handbook published by the United States Steel Corporation (U. S. Steel, 1963.) Here the concern is with the wire rope types that best suit special needs of deep ocean anchorages. At present, no one cable type combines the optimum composition and construction factors to achieve all the desirable characteristics that eventually may be attainable. A compromise is necessary.

The wire rope type that appears best to offer such compromise is the extra-improved plow-steel, galvanized, regular lay, 6 by 19 filler wire with an independent wire rope core (Beck, 1962). The wires should be galvanized by a drawing process rather than hot-dipped, as the hot-dip process reduces rope strength, and heavy marine lubricant should be applied during layup. (One item of note concerning lubricants for wire ropes is that in the tropics excess lubricant from a new rope drips onto the deck and gets tracked all over the ship.) The wires should be preformed. Use of the extra-improved plow steel provides about 15 percent more strength than improved plow steel. The galvanizing increases resistance to corrosion. The independent wire rope core resists crushing or flattening of the rope over a sheave, besides adding strength, and also prevents the bridging or contact between outer strands which restricts free movement and leads to fatigue. Advantages of regular lay rope construction are several. The reverse twist produced by twisting the wires in one direction to form the strands and the strands in the opposite direction to form the rope, reduces the tendency of the rope to unlay or kink. Regular lay ropes also resist crushing and distortion quite well. Preforming of the wires removes internal stresses, leaving the wires relaxed in their normal positions in the rope and reducing the liveliness and the untwisting effect. The general construction gives reasonable flexibility and good abrasion resistance, since the exposed wires are large. The type of wire rope just described was used in the TOTO II installation.

Stainless steel cable has been tried for long-term suspension of vertical strings in the ocean (Beck, 1962). Its anticorrosion properties are good, but it is expensive and has poor fatigue characteristics. Probably the 400 series stainless steel is superior to the 300 series for use in deep ocean anchorages.

In using wire rope in very deep water, a large portion of the total load on the cable near the surface is due to the weight of the cable. It is possible to partially overcome this effect by using a tapered rope. In this manner the working strength of the smaller diameter cable at the bottom is available for the payload. The disadvantage of this approach to wire rope design is that a variety of cable sizes must be stocked and handling problems are intensified.

Methods of protecting wire rope cables from corrosion by providing coatings are being investigated. Some cables have been coated in plastic sheathing. Cupro-nickel coating has been tried with reported success (Frieling, 1964). Coatings, however, present problems in handling and placement. Damage can occur to the coating at different locations, resulting in rapid deterioration of the cable at these points.

A summary of wire rope strength characteristics is given in Table 3-1.

Table 3-1. Wire Rope Strength Characteristics (High-Grade Plow-Steel IWRC Rope)

(Data from United States Steel Wire Rope Handbook for Western Wire Rope Users)

Nominal Diameter (in.)	Dry Weight (lb/ft)	Wet Weight* (lb/ft)	Breaking Strength (lb)	Breaking Length (ft)
1/4	0.12	0.10	5,880	56,400
1/2	0.44	0.38	23,000	60,500
3/4	0.99	0.86	51,200	59,500
1	1.76	1.53	89,800	58,700
1-1/4	2.66	2.31	132,200	57,200
1-1/2	3.84	3.34	189,000	56,600
1-3/4	5.23	4.54	256,000	56,400
2	6.82	5.93	330,000	55,900
2-1/4	8.64	7.51	414,000	55,100
2-1/2	10.66	9.26	508,000	54,900
2-3/4	12.89	11.20	610,000	47,300
3	15.35	13.34	720,000	54,000
3-1/4	18.01	15.65	838,000	53,500
3-1/2	20.90	18.16	966,000	53,200
3-3/4	23.98	20.84	1,098,000	52,700
4	27.28	23.71	1,240,000	52,300

*Salt Water

3-12. Nonmetallic Ropes. As a group the nonmetallic ropes offer advantages over metallic ropes, but as yet these have been used primarily in anchorages for smaller structures such as buoys. Of the nonmetallic ropes, synthetic types appear to offer the greatest potential for deep ocean anchorages. Characteristics of the more prominent materials of composition are presented in the following paragraphs.

(a) Manila. Used extensively for ship-to-shore berthing of vessels and for rigging operations, manila rope in deep-ocean anchorage application is of value primarily in support working during installation procedures. In this respect it is of high value whether the connecting apparatus is metallic or nonmetallic rope. Manila is unequaled for combined economy, strength, flexibility, and ease of handling in general-purpose rigging service.

(b) Nylon. The finest performing nonmetallic rope available is nylon. It possesses extremely high strength (35,000 to 37,000 psi cross section) and outstanding resistance to breaking by shock loads. It has good resistance to attack by oils, solvents and alkalis, will not rot or mildew and can be stored wet. Nylon can be obtained in regular lay and in braided types of construction with or without a center core. It has a low density of about 1.1, making it nearly weightless in water. The chief disadvantage of nylon rope is cost, which is about three times that of manila rope of comparable size. Also, according to Pickett (1963), nylon rope permanently elongates under heavy loading.

(c) Dacron. Dacron rope can be obtained in twisted or braided construction. It has high strength, about 77 percent that of nylon, high abrasion resistance and low elasticity. It is better than nylon for use under acid conditions. It is resistant to the effects of sunlight and its wet strength is as good as its dry strength. Dacron rope is about 2 percent heavier than nylon, but still is very lightweight in water. It is an important component of the connecting apparatus of the NOMAD buoy anchorage system described in paragraph 4-6. The cost of dacron rope approximates that of nylon.

(d) Polypropylene. This synthetic rope has gained high favor for use in anchorages for buoys. It has good strength, about 60 percent that of nylon rope. Lightest of the synthetic ropes, it is buoyant in water, a property enabling it to utilize its full working strength to resist applied loads whatever the depth of the anchor to which it is attached. It is rotproof, mildewproof, has low elasticity and good low-temperature flexibility. It is unaffected by moisture and can be stored wet. The cost is about one-third that of nylon and dacron rope. There are conflicting reports on the performance of polypropylene rope in sea water. Richardson (1963) reports that under continuous strain it elongates and its effective cross section resisting stress is reduced, thus reducing its maximum capacity. Scientists at Scripps Institution of Oceanography believe polypropylene loses up to 40 percent of its load-carrying capacity when subjected to continuous applied load. Conversely, Huntly (1963), designer of the anchorages for Project DOMINIC, stated that polypropylene rope had evidenced no deterioration for periods up to 18 months. Pickett (1963) also says that tests indicate that 90 percent of breaking strength is retained after 6 months of loading.

Polypropylene rope can be obtained in braided and regular lay constructions. A multifilament type is available that has the same characteristics as the monofilament type, but is of higher strength and durability.

(e) Polyethylene. This rope is composed of polyethylene fibers with or without a center core of like fibers. It can be obtained in either regular lay or braided form. It is approximately neutrally buoyant and will remain so over an indefinite period. Like nylon, polyethylene is impervious to mildew and rot. Its wet strength is equal to dry strength, the tensile strength about 50 percent that of nylon rope, and dielectric strength excellent, making its use advantageous around electrical equipment. It is unaffected by moisture and has good low-temperature flexibility. The cost is approximately one-third less than that of nylon rope. Polyethylene has been used in anchorage installation for riser lines with an electrical wire core to transmit electronic signals.

(f) Fiber Glass. Fiber-glass ropes are under development. They offer promise of high strength and extremely high resistance to deterioration from any source in the marine environment. The primary difficulty at present appears to be in overcoming brittleness. According to Costello (1963-64), one fiber-glass rope has been developed which eliminates the brittleness factor and has a strength of 200,000 psi. As far as is known, no anchorages have been installed that utilize fiber-glass ropes for connecting apparatus.

(g) Summary. The light weight and general ease of handling of nonmetallic ropes in general enhance their use in placement operations and permit maximum utilization of rope strength to resist actual working loads instead of dissipating part of the strength in supporting the rope's own weight. In lowering operations the buoyant or near-buoyant characteristics of these ropes allow good sensitivity of the load as it touches bottom.

The synthetic ropes appear to be highly resistant to the general effects of the marine environment. However, as noted elsewhere in this chapter (paragraph 2-12), they are subject to attack and damage by large marine creatures. It is believed, as reported there, that black ropes attract less attention and are less subject to these attacks than lighter colored ropes. Braided construction is considered advantageous (Figure 3-10). Though more expensive, this feature is essential in eliminating undesired and extremely detrimental torque in ropes. A regular lay-constructed synthetic rope will unlay and kink as severely as the metallic ropes, and the effect on both the installation and the rope is equally disastrous.

Whatever their future in deep ocean anchorages may ultimately be, synthetic ropes should prove valuable for use in slack-line moorings and as pendant lines between various elements of anchorages and structures being anchored. Their buoyancy, flexibility, and elasticity are decided assets.

Rope strength ratios for natural, synthetic and metallic ropes are given in Table 3-2.

Figure 3-10. Comparison of braided and regular lay rope construction.

Table 3-2. Rope Strength (Strength-to-Diameter) Ratios for Natural, Synthetic, and Metallic Ropes (Pounds per Square Inch Cross Section)

Nominal Diameter (in.)	Nominal Area (sq in.)	Manila 1/ (lb/sq in.)	Nylon 1/ Fiber (lb/sq in.)	Dacron 1/ Fiber (lb/sq in.)	Polypropylene 1/ Fiber (lb/sq in.)	Steel 2/ Strand (lb/sq in.)
1/4	0.049	12,200	40,000	43,900	27,600	120,000
1/2	0.196	13,500	36,700	38,800	21,400	117,300
3/4	0.442	12,200	34,600	35,300	18,600	115,800
1	0.785	11,500	33,800	31,800	17,800	114,400
1-1/4	1.227	11,000	33,800	24,900	16,900	107,700
1-1/2	1.767	10,500	34,000	25,500	16,800	107,000
1-3/4	2.405	11,000	37,400	27,600	18,300	106,400
2	3.142	9,900	34,000	24,500	16,900	105,000
2-1/4	3.976	10,300	36,500	26,900	17,600	104,100
2-1/2	4.909	9,500	33,800	24,400	16,400	103,500
2-5/8	5.940	9,600	32,000	23,100	15,200	102,700
3	7.069	9,100	34,000	25,500	16,100	101,900
3-1/4	8.296	9,300	36,200	26,400	16,500	101,000
3-1/2	9.621	9,500	37,400	28,100	16,800	100,400
4	12.566	8,400	34,200	26,000	15,100	98,700

1/ Natural and synthetic rope data from Plymouth Cordage Company.

2/ Steel strand data from United States Steel Wire Rope Handbook for Western Wire Rope Users.

3-13. Chain

Both die-lock and cast steel chain have been used in deep ocean anchorages. However, the standard mooring chain used in harbor moorings is the die-lock forged steel. It has greater strength and shock resistance than cast steel chain, but is more expensive. Chain is also available in special steels, but the use of these is extremely expensive and apparently unjustified.

The weight, massiveness, and the resultant problems in handling of chain make its use throughout a deep-ocean anchorage system completely impractical. Also, the cross-sectional area exposed to possible ocean currents is greater for chains than ropes, and in the great lengths involved the forces on the system can become excessive. However, there are factors favoring use of chain at the bottom and upper extremities of a system. On the bottom, chain helps impart the horizontal load component on the anchor. Use of chain as an anchor is contemplated for mooring a 50,000-pound discus-type buoy, as described in paragraph 7-2. The capacity of chain to withstand abuse and the fact that it can be easily attached to or connected with standard fittings and connections makes it use frequently desirable at upper extremities of anchorages. Some characteristics of chain are listed in Table 3-3.

3-14. ACCESSORIES.

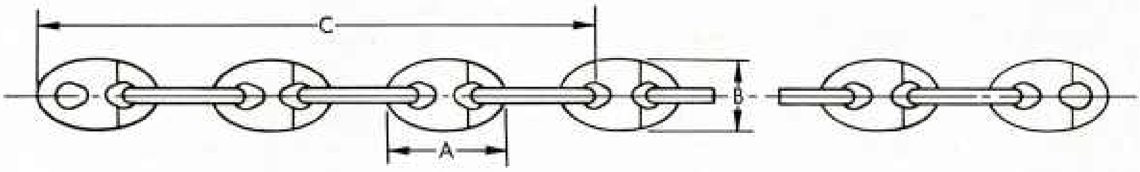
Accessories and special features serve important functions in installing deep ocean anchorages and in maintaining their integrity. They are discussed here in terms of "separation devices" and "auxiliary accessories."

3-15. Separation Devices.

Separation and release devices are incorporated into anchorage designs to provide a separation or breakage point at a convenient location in the connecting apparatus in order to protect valuable features of an installation against excessive forces, or to assure that they may be recovered if desired. For example, many buoys support instruments and other devices that must be examined periodically. By placing a separation device in the system, below the instruments, the instruments can be lifted from the ocean with less risk of loss if the anchor becomes embedded beyond the capacity to extract it. Furthermore, in anchoring types of structures other than buoys, it is sometimes necessary to release part of the anchorage system for removal or examination; and in case of failure, a separation device can be designed and strategically placed so that most of the gear and apparatus can be recovered.

3-16. Weak Links. The weak link is a major type of separating device and may be of two basic varieties, structural and hydraulic. In the structural type (Figure 3-11), one section of the connecting system is constructed of material structurally weaker than the rest of the apparatus. This can be accomplished by making the weak link of the same material, but of lesser dimensions, by making it of another material possessing less strength, or by making it in a different structural shape. The hydraulic type of weak link (Figure 3-12) is held together by the ambient hydrostatic pressure acting on a piston. Such links have been included in buoy anchorages as described by Richardson (1963).

Table 3-3. Properties of Stud-Link Chain



All dimensions in inches.

Chain Size	Link Length (A)	Link Width (B)	Length Over Six Links (C)	Links Per 15-Fathom Shot*	Weight Per 15-Fathom Shot* (Approx)	Wrought Iron		Cast Steel		DI-LOK	
						Proof Test (lb)	Break Test (lb)	Proof Test (lb)	Break Test (lb)	Proof Test (lb)	Break Test (lb)
1/2	3	1-13/16	13	535	340	10,300	15,400	15,900	22,300	22,100	34,000
9/16	3-3/8	2	14-5/8	475	358	13,000	19,450	19,950	27,900	27,900	42,400
5/8	3-3/4	2-3/16	16-1/4	427	385	15,680	23,560	24,560	34,380	32,300	52,200
11/16	4-1/8	2-7/16	17-7/8	389	425	19,040	28,560	29,400	41,160	41,300	61,800
3/4	4-1/2	2-5/8	19-1/2	357	505	22,680	33,880	34,680	48,550	48,000	75,000
13/16	4-7/8	2-7/8	21-1/8	329	600	26,600	39,872	40,430	56,600	56,000	86,500
7/8	5-1/4	3-1/8	22-3/4	305	700	30,800	46,200	46,630	65,280	64,000	98,000
15/16	5-5/8	3-5/16	24-3/8	285	795	35,392	53,088	53,280	74,590	74,000	113,500
1	6	3-9/16	26	267	900	40,320	60,480	60,360	84,500	84,000	129,000
1-1/16	6-3/8	3-3/4	27-5/8	251	1,020	45,472	68,096	67,850	94,990	95,000	145,000
1-1/8	6-3/4	4	29-1/4	237	1,140	50,960	76,440	75,770	106,080	106,000	161,000
1-3/16	7-1/8	4-1/4	30-7/8	225	1,275	56,840	85,120	84,120	117,770	118,000	179,500
1-1/4	7-1/2	4-1/2	32-1/2	213	1,415	63,000	94,360	92,910	130,070	130,000	198,000
1-5/16	7-7/8	4-3/4	34-1/8	203	1,560	69,440	104,160	102,090	142,930	143,500	216,500
1-3/8	8-1/4	4-15/16	35-3/4	195	1,705	76,120	114,240	111,660	156,330	157,000	235,000
1-7/16	8-5/8	5-3/16	37-3/8	187	1,865	83,160	124,600	121,720	170,430	171,000	257,500
1-1/2	9	5-3/8	39	179	2,035	90,720	131,488	132,190	185,060	185,000	280,000
1-9/16	9-3/8	5-5/8	40-5/8	171	2,195	98,336	137,536	143,050	200,270	200,500	302,500
1-5/8	9-3/4	5-7/8	42-1/4	165	2,345	106,400	148,960	154,310	216,030	216,000	325,000
1-11/16	10-1/8	6-1/16	43-7/8	159	2,530	114,800	160,720	165,960	232,360	232,500	352,500
1-3/4	10-1/2	6-5/16	45-1/2	153	2,720	123,480	172,760	178,000	249,210	249,000	380,000
1-13/16	10-7/8	6-1/2	47-1/8	147	2,925	132,440	185,360	190,430	266,620	267,000	406,000
1-7/8	11-1/4	6-3/4	48-3/4	143	3,125	141,680	198,240	203,250	284,540	285,000	432,000
1-15/16	11-5/8	7	50-3/8	139	3,335	151,200	211,680	216,430	303,000	303,500	460,000
2	12	7-3/16	52	133	3,525	161,280	225,792	230,000	322,000	322,000	488,000
2-1/16	12-3/8	7-7/16	53-5/8	129	3,750	171,360	239,904	243,930	341,510	342,000	518,000
2-1/8	12-3/4	7-5/8	55-1/4	125	3,975	182,000	254,800	258,240	361,530	362,000	548,000
2-3/16	13-1/8	7-7/8	56-7/8	123	4,215	192,920	269,920	272,910	382,060	382,500	579,100
2-1/4	13-1/2	8-1/8	58-1/2	119	4,460	204,120	285,600	287,930	403,100	403,000	610,000
2-5/16	13-7/8	8-5/16	60-1/8	117	4,710	215,600	301,840	303,320	424,630	425,000	642,500
2-3/8	14-1/4	8-9/16	61-3/4	113	4,960	227,360	318,304	319,050	446,660	447,000	675,000
2-7/16	14-5/8	8-3/4	63-3/8	111	5,210	239,456	335,160	335,130	469,180	469,500	709,500
2-1/2	15	9	65	107	5,528	252,000	352,800	351,560	492,190	492,000	744,000
2-9/16	15-3/8	9-1/4	66-5/8	105	5,810	261,408	365,960	368,340	515,670	516,000	778,500
2-5/8	15-3/4	9-7/16	68-1/4	103	6,105	270,816	379,120	385,440	539,620	540,000	813,000
2-11/16	16-1/8	9-11/16	69-7/8	99	6,410	280,224	392,280	402,890	564,040	565,000	849,000
2-3/4	16-1/2	9-7/8	71-1/2	97	6,725	289,632	405,440	420,660	588,930	590,000	885,000
2-13/16	16-7/8	10-1/8	73-1/8	95	7,040	298,816	418,320	438,760	614,260	615,000	925,000
2-7/8	17-1/4	10-3/8	74-3/4	93	7,365	308,224	431,480	457,190	640,070	640,000	965,000
2-15/16	17-5/8	10-9/16	76-3/8	91	7,696	317,408	444,360	475,940	666,310	666,500	1,005,000
3	18	10-13/16	78	89	8,035	326,592	457,184	495,000	693,000	693,000	1,045,000
3-1/16	18-3/8	11	79-5/8	87	8,379	335,552	469,728	514,380	720,130	720,500	1,086,500
3-1/8	18-3/4	11-1/4	81-1/4	85	8,736	344,400	482,160	534,060	747,680	748,000	1,128,000
3-3/16	19-1/8	11-1/2	82-7/8	85	9,093	353,248	494,480	554,050	775,670	776,050	1,169,000
3-1/4	19-1/2	11-11/16	84-1/2	83	9,460	361,984	506,688	574,340	804,070	804,100	1,210,000
3-5/16	19-7/8	11-15/16	86-1/8	81	9,828	370,496	518,560	594,920	832,890	883,150	1,253,000
3-3/8	20-1/4	12-1/8	87-3/4	79	10,210	378,840	530,320	615,800	862,130	862,200	1,296,000
3-7/16	20-5/8	12-3/8	89-3/8	77	10,599	386,960	541,632	636,970	891,770	892,100	1,339,550
3-1/2	21	12-5/8	91	77	10,998	395,136	553,056	658,440	921,810	922,000	1,383,100
3-5/8	21-3/4	12-15/16	94-1/4	73	11,607	410,253	570,688	702,755	983,850	1,021,000	1,566.000
3-3/4	22-1/2	13-3/8	97-1/2	71	12,626	425,370	588,320	747,070	1,045,900	1,120,000	1,750,000

*1 shot = 15 fathoms (90 feet).

In general, individual design requirements influence the selection of type of weak link for a particular system. The larger capacities probably require the structural type, whereas both the structural and hydraulic types can be used in smaller capacity anchorages. The advantage of the weak link is its simplicity. The disadvantages are that the strength of the moor is necessarily reduced to the safe-working-load level of the weak link. Consequently, economy of materials is not obtained because a large quantity of strong material is limited to the strength of the weak link. Another serious handicap is that deterioration rates are not known and it is conceivable the weak link might not be the weakest point in the system after a period of service. Furthermore, weak links of the conventional type release by application of brute force, and not by convenient triggering.

3-17. Triggered. Other release and separation devices require triggering. These include mechanisms such as links, bolts, or section of a cable which are broken by impulse, chemical action, or other physical means. They are more versatile than weak links. According to Schick (1961), triggering actions for these release devices can be of three general types: (1) time delay, (2) pressure, and (3) impulse. The time-delay device depends on a physical process such as the melting of ice or dissolving of salt. Some clockwise devices likewise have been used to produce a delayed mechanical motion. The pressure-type device depends upon the ambient pressure of the water environment for its functioning. It may be designed around a pressure fuse that makes use of a thin-metal rupture disk whose rupture pressure can be accurately determined experimentally. The impulse-type device is designed to react to sound or electrical impulses.

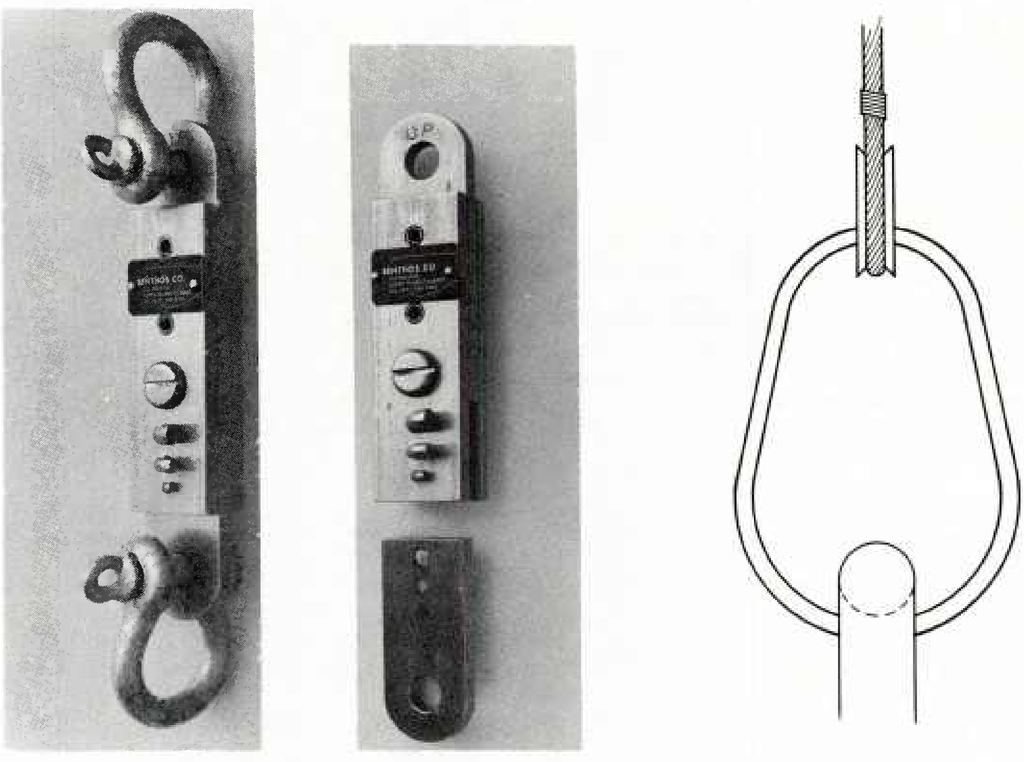


Figure 3-11. Structural types of weak link.

Photo©Benthos Co.

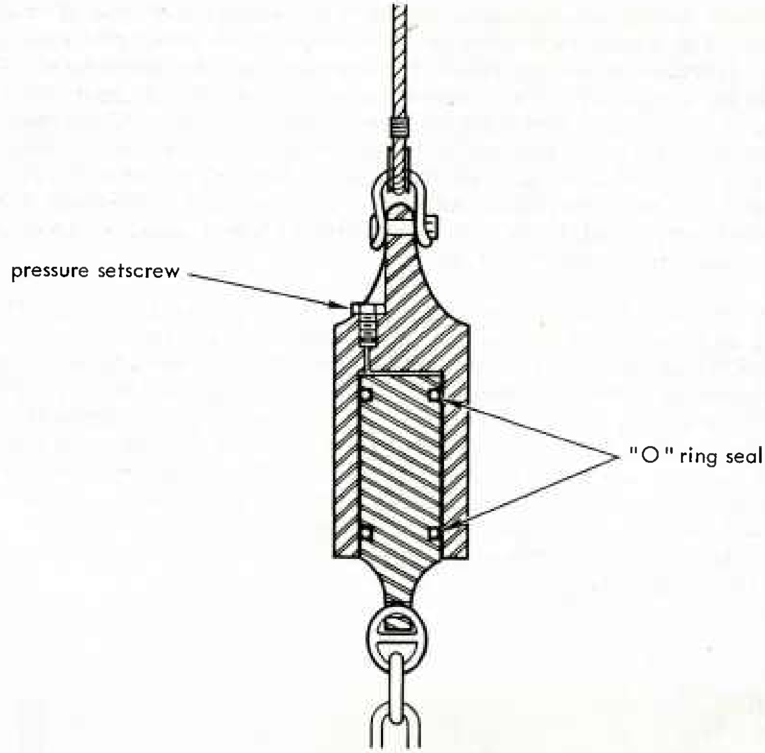


Figure 3-12. Hydraulic type of weak link.

An acoustic type of release consists of a sensitive hydrophone or detector that is tuned to receive through a servomechanism a coded signal from the service ship. The signal actuates an explosive charge, a vacuum release, or a motor that accomplishes the separation. A newly developed acoustically commanded release device available in capacities from 500 to 50,000 pounds (Figure 3-13) has a reported depth capability of 20,000 feet, service life of one year, and command range of 5 miles or more horizontally (AMF, 1964). It has a mechanical release mechanism that is non-pressure sensitive and does not require an explosive bolt, is equipped with a reply pinger, and has a shipboard command transmitter capable of various coded commands.

Explosives can be efficient separation devices, and a number of designs have been perfected that function to depths of at least 4,000 feet (Barlog, 1964). An explosive-type separator used by Woods Hole Oceanographic Institution is shown in Figure 3-14a. A type of explosive release bolt is being commercially produced (Hydro Products, 1964). It is a positive release device (Figure 3-14b) using a power source of 1.5 volts. It is "No Fire" at 0.2 amperes and "All Fire" at 2.0 amperes, load rated at 1,000 pounds, and leakproof tested to over 5,000 psi. It can be acoustically actuated using a preset coded transponder, fired by either mechanical means or use of a time-delay device. It is now being used by the U. S. Naval Research Laboratory, Columbia University, and NATO countries. Release devices having load ratings up to 20,000 pounds are also available.

Selection of a suitable triggering device depends on the operation to be performed, depth of water, size and weight of component being handled, and precision required. The time-delay is perhaps least expensive. If ultimate sure release on the bottom is the prime consideration, this device is likely to be most satisfactory. However, precise determination of time for release is not possible because of unknown factors that affect the decomposition rate of the material used for triggering. Some of these factors are temperature and composition of water, depletion of chemical constituents of the water, effect of movement of the device through the water, and variations in quality and composition of the triggering material.

If release is desired at a specific depth, the pressure-type release is reported as accurate to within 2 to 3 percent (Schick, 1961). This type of device is probably the second least expensive and is highly reliable. Figure 3-15 illustrates the type of pressure release successfully used at Scripps Institution of Oceanography to release a ballast weight from a large free net that was launched from a ship and allowed to sink to a predetermined depth. It was triggered by a pressure fuse.

The impulse type of trigger may well be selected for situations when release must be attained upon command as dictated by circumstances surrounding the placement or recovery operation. This type is the most sophisticated and expensive and to date probably the least reliable (Schick, 1961). Communication must be provided between active and passive elements of the device either by electrical connection or by sound waves through the water.

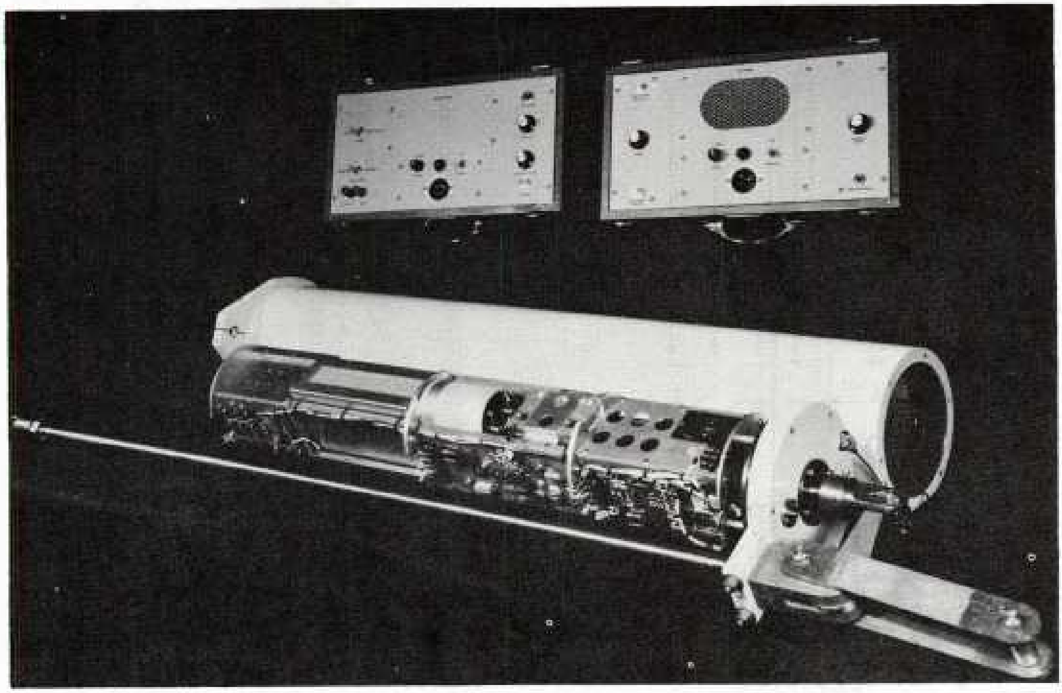
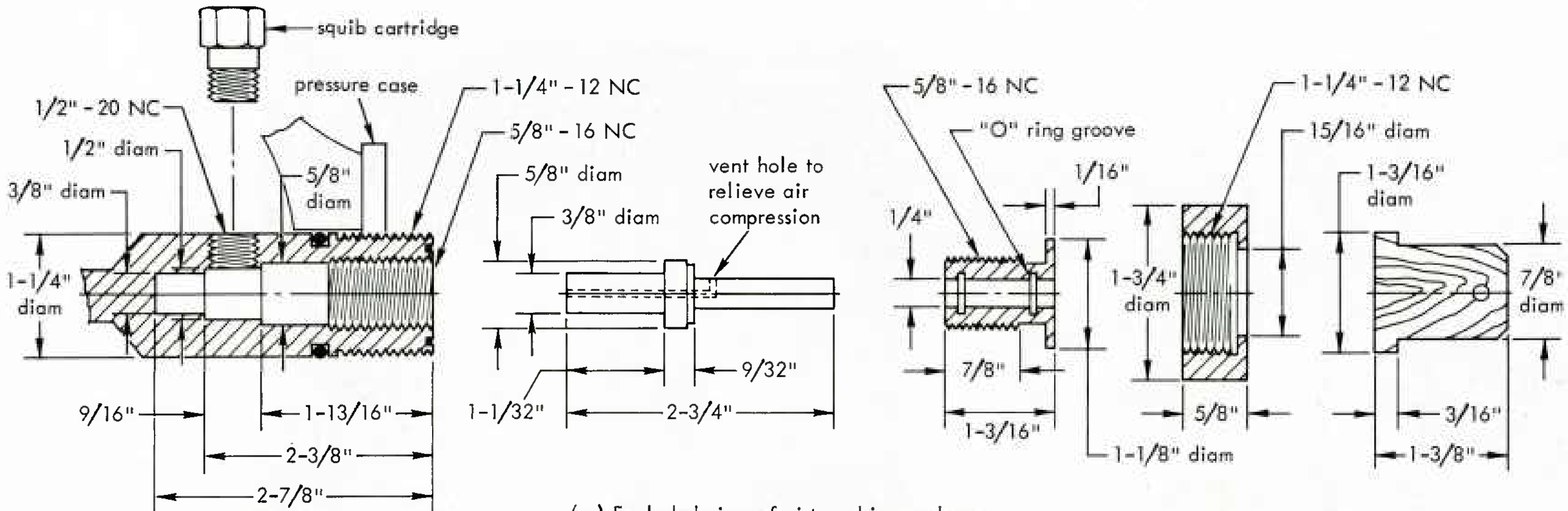
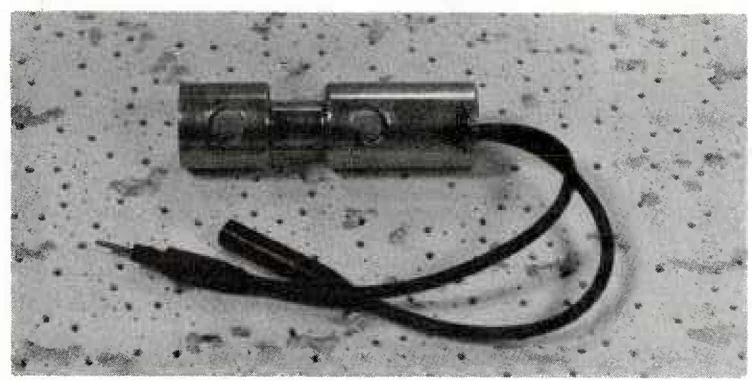


Figure 3-13. Acoustically commanded release device.



(a) Exploded view of piston-driven release
©Woods Hole Oceanographic Institution



(b) Commercially produced explosive release
©Hydro Products, a Division of Oceanographic Engineering Corp.

Figure 3-14. Explosive type separation devices.

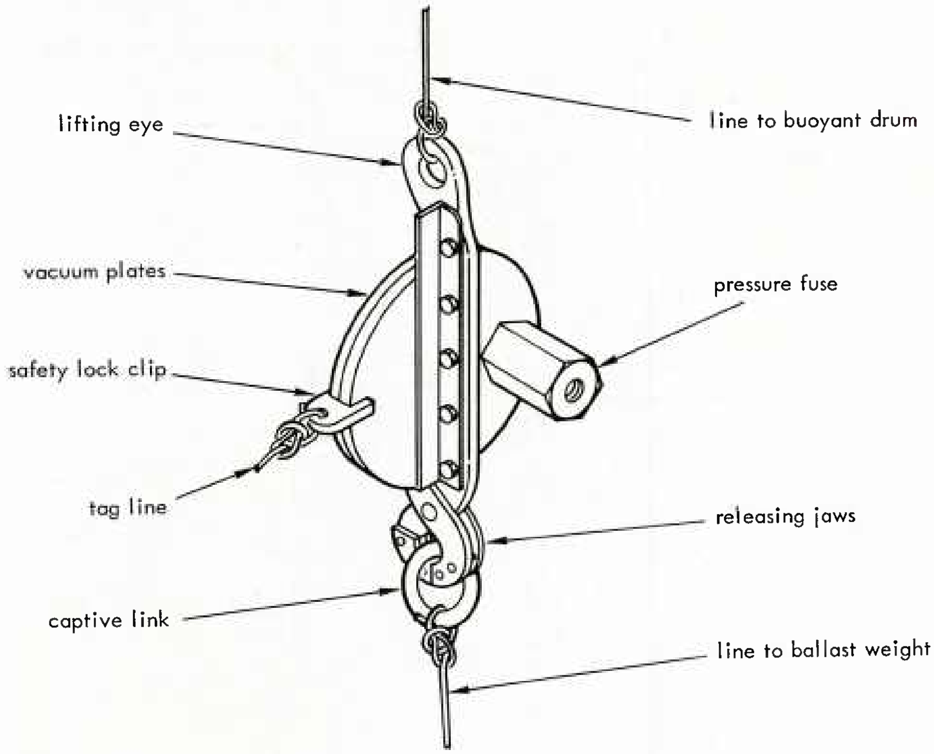


Figure 3-15. Pressure type of triggered release.

3-18. Auxiliary Accessories.

3-19. Bottom Detectors. Bottom-detecting devices are important in the placement of an anchor or other weight on the ocean floor. At some distance above the bottom it is essential that the lowering process be slowed, so that the lowering line will not be relieved of the weight too suddenly and become kinked, tangled, or damaged. A simple device for detecting the bottom used by Scripps Institution of Oceanography is described by Isaacs (1963). A 150-foot pendant line carrying the device is suspended below the weight being lowered (Figure 3-16). The bottom-detecting device, on contact with the bottom, allows a solid steel piston, weighing about 30 pounds and fitted with a sharp fluted point, to fall onto a small glass ball 3 inches in diameter. The glass ball rests against another steel mass and the impact of the piston causes it to rupture with a violent implosion that can readily be detected at the surface.

3-20. Pingers. A pinger is an automatic transmitter that emits preset sound signal patterns. It is used in buoy anchorage systems to help locate submerged buoys or other components. The pinger can be actuated by coded signals from surface craft, be preset to commence signals after a definite time lapse, or be adjusted to emit signals after some operation or action such as the separation of a submerged buoy from the system. The pinging provides a guide to the location of a buoy system or can serve to indicate a specific occurrence or action.

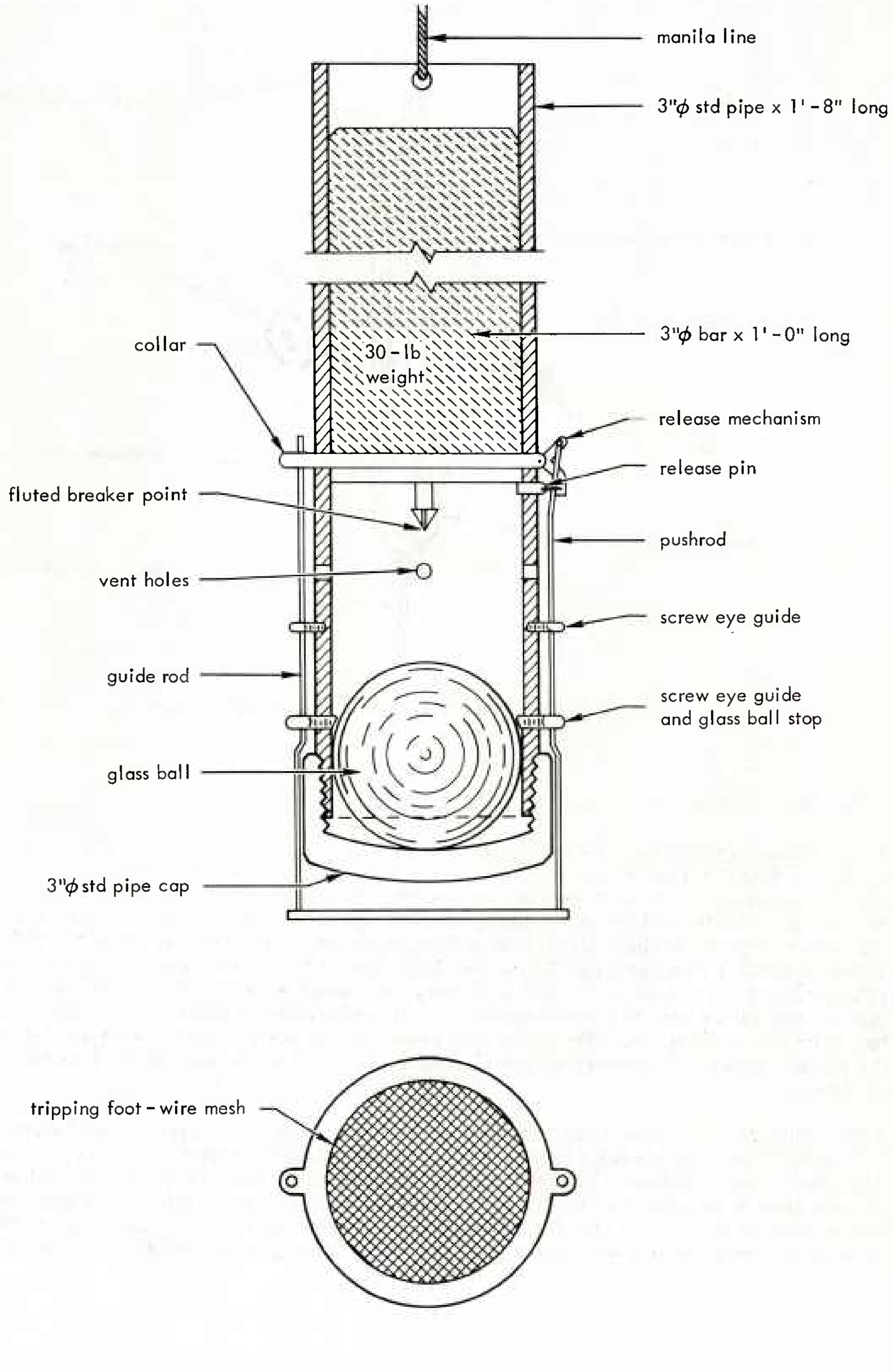
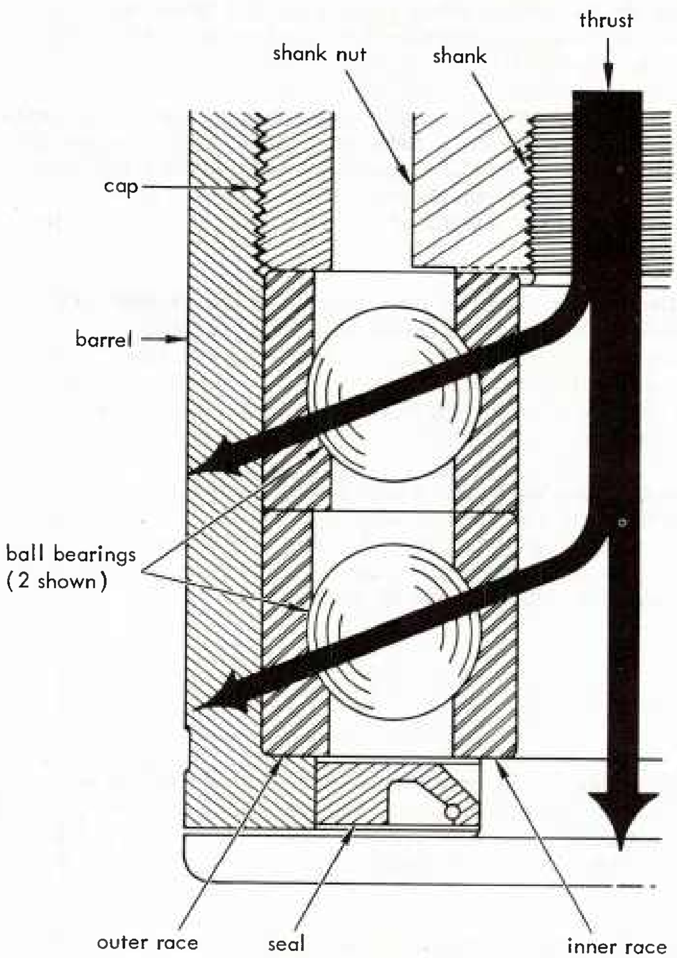


Figure 3-16. Impact type of bottom detector. (Isaacs, 1963)



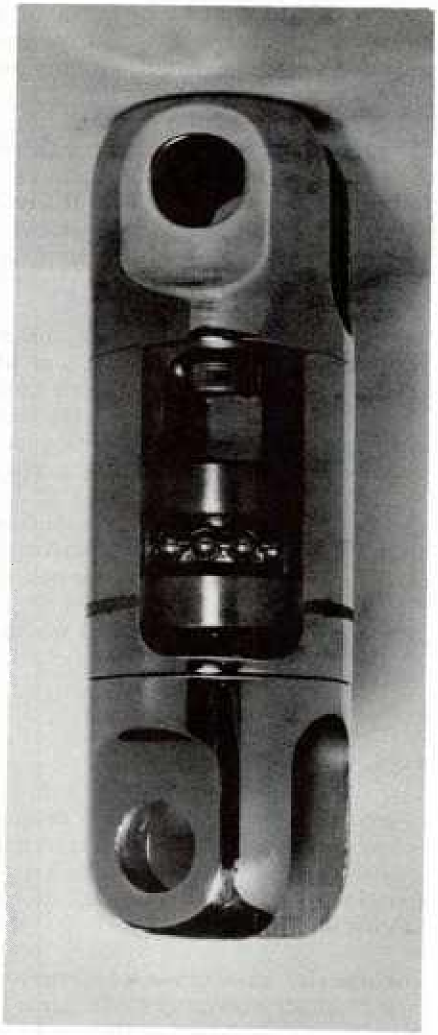


Figure 3-17. Patented Miller swivel.

3-21. Connectors. Connectors are not only highly useful hardware in deep ocean anchorage systems but often vital elements for their proper functioning. Principal types are described in the following paragraphs.

(a) Swivels. Swivels are devices inserted in mooring lines or chains to permit rotation. Used in deep ocean anchorage systems, they must provide complete freedom of rotation under extreme conditions of slack and tension. They must be capable of withstanding shock loadings, be resistant to corrosion, and remain operational at deeply submerged levels for indefinite periods with no servicing. One swivel that appears to most nearly attain these objectives is the Miller swivel (Miller Products, 1964) shown in Figure 3-17. This swivel has been specified for use in a number of deep-ocean anchorage systems.

Conventional swivels may be useful near the surface where they can be inspected and serviced. At deeper levels, however, their rotating mechanism is likely to corrode and make them inoperable (Jones, 1964). A common type of swivel wherein the bolt head rotates in a collar and joins two parts of an anchor is shown in Figure 3-18.

(b) Ground Rings. These cast or forged metal rings are used to connect various components of the ground tackle of an anchoring system. An example of their application is the Tongue of the Ocean Anchorage, TOTO II (Hydrospace, 1964). In this installation the ground rings were used in the connections between the lower catenary and the upper catenary legs. Coincidentally, they comprised the attaching unit for the string of six anodes providing cathodic protection for the connecting apparatus.

(c) Flounder Plates. Sometimes called spider plates, these are cast-steel, triangle-shaped plates containing three holes, one hole being elongated and larger than the other two (Figure 3-19). Flounder plates were also used in the TOTO II anchorage (Hydrospace, 1964). The three span wires joining the three upper catenary legs of the system were united under 2,000 pounds' tension by the flounder plate's maintaining the tension of these wires while in position 15 feet below the sea surface.

(d) Thimbles. The principal function of thimbles - pear-shaped steel castings grooved to accept a particular-sized metallic or nonmetallic rope - is to alleviate wear on the rope where connections other than splices are made, usually by means of a shackle. Thimbles were formerly used extensively with wire rope, but the present practice favors the use of steel wire rope with an open socket cast which obviates the need of a splice and thimble.

3-22. MATERIALS.

3-23. General Application.

In general, materials used in deep ocean construction should possess high strength and be economical and long-lived; large quantities are usually required; installation is extremely expensive; and maintenance or repair is difficult if not impossible. Other desirable qualities apply separately to metals and nonmetals according to how, where, and for what purpose they are used.

For metals, resistance to corrosion and resistance to abrasion are of high importance. The latter chiefly concerns those parts of an anchorage system in contact with the bottom. Aluminum and stainless steels currently are popular metals for many uses in buoy anchorages, with titanium also employed. For nonmetals, resistance to deterioration, resistance to fouling, flexibility, light weight, and ease of handling are desirable characteristics. A brief list of materials, their properties, and uses are given in Table 3-4.

Important factors in the selection of materials for undersea construction are cost and availability. Often items such as shackles, thimbles, or other parts are not readily available in the material desired. Consequently, a less desirable material must be accepted to prevent undue delay. As progress in undersea work is made, availability of items, in particular exotic materials, should become less of a problem.

3-24. Buoyancy.

It may be necessary or advantageous to provide buoyancy for individual components, or for sections of an anchorage system, between the bottom implement and surface. Investigations aimed at achieving good buoyancy at great depths at more economical costs are underway. The following summary of the current status of providing buoyancy is based on an article by Lippman (1963).

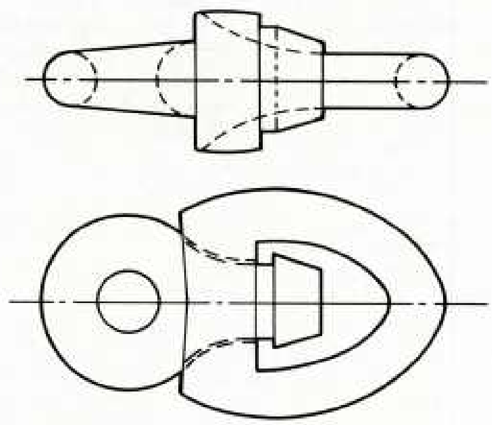


Figure 3-18. Common chain swivel.

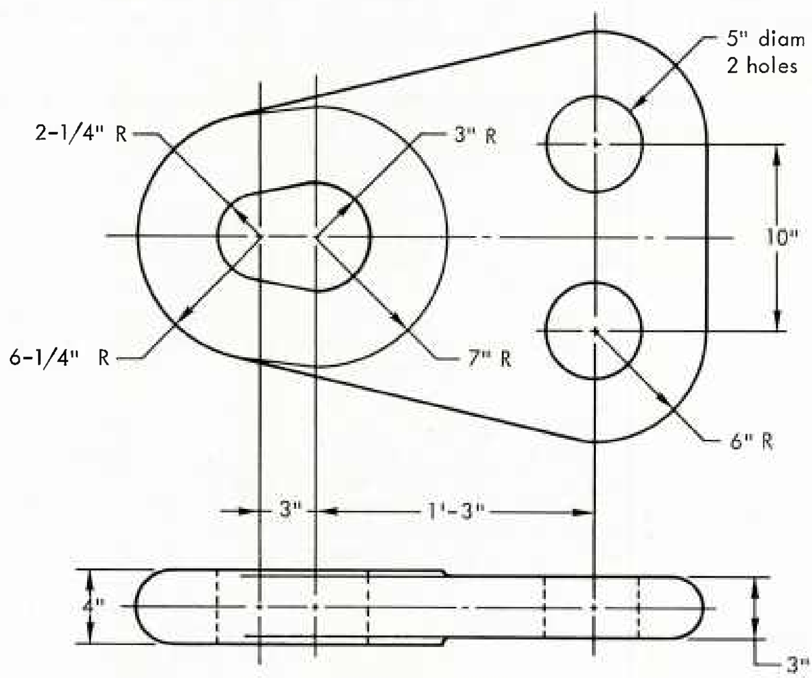


Figure 3-19. Flounder plate.

Table 3-4. Materials Used in Deep Ocean Constructions

	Material	General Characteristics	Uses
Metals	Aluminum 6061 - Fed. QQ-A-3276	Relatively high strength; good workability; high resistance to corrosion; widely available	Pressure vessels, fittings, connections, flanges
	Stainless Steel - AISI 303	High strength; good machinability; fair resistance to corrosion; good resistance to abrasion; not good for welding (welds should be annealed after welding for resistance to corrosion)	Fittings, connections, cables
	Stainless Steel - AISI 316	High strength; good resistance to corrosion; good resistance to abrasion; good for welding; poor machinability	Fittings, connections, cables
	Titanium (various alloys, with iron, aluminum, silicon, molybdenum)	Uniquely high resistance to corrosion; easily welded in inert atmosphere; high strength; formability	Fittings, flanges, connections, wires, containers, tools
Nonmetals	Polypropylene	Lightest of all thermoplastics (buoyant); moderate tensile and flexural strength; excellent dielectric strength; does not mildew or rot	Rope, lines, cords, rods
	Polyurethane	Moderate strength; rotproof; good flexibility at low temperatures	Cord, line, containers, tubing
	Polyvinyl chloride (polyvinyl chloride, polyvinyl chloride-acetate, and vinylidene chloride)	Moderate to excellent resistance to acids and common alkalis; excellent corrosion resistance	Gasket, rods, flexible tubing and pipe, chemical containers, appliance and machine tool cords, hoses, valves
	Nylon	Extremely high strength; outstanding resistance to breaking by shock loads; good resistance to attack by oils, solvents, alkalis; does not rot or mildew; extremely tough; good abrasion resistance	Rope, cord, line, fittings, tubing, rods
	Dacron	High strength; high abrasion resistance; low elasticity; does not rot or mildew	Rope, line, cord
	Teflon	Unaffected by most known chemicals; nonadhesive; extremely low coefficient friction; zero moisture absorption; excellent dielectric strength and arc resistance properties	Packing, rods, tubes, tubing, bearing, surfaces, expansion joints
	Common Glass	*Unusually high compressive strengh; relatively low weight; excellent resistance to corrosion; translucent; outstanding strength-to-weight ratio compared to other hull materials	Pressure vessels and hulls, pressure floats
	Rubber (butadiene-acrylonitrile compound)	Abrasion resistant; corrosion resistant	Sealants, "O" rings, packing, diaphragms

*Tested at David Taylor Model Basin.

Currently, the four basic means of achieving buoyancy include the use of (1) rigid hollow bodies, (2) low-density solids, (3) low-density liquids, and (4) low-density gases. The most important characteristics to consider in selecting a buoyancy material are the amount of buoyancy provided for a given weight or volume, and the cost per given amount of buoyancy. These characteristics can be expressed by ratios of buoyancy to weight, buoyancy to volume, and cost to buoyancy. None of the materials currently available, or under development, is superior in all respects. Thus, the advantages and disadvantages of each should be evaluated carefully.

Buoyancy-weight ratio of material can be obtained from the expression $(1.03-d)/d$ where 1.03 is the density of sea water and d is the density of the float material, both in grams per cubic centimeter. This formula and those following pertain only to the buoyant material, not to the complete float or buoyancy unit. In most cases these will include nonbuoyant parts that are not negligible. If d is greater than 1.03 gm per cc, the material is negatively buoyant; i.e., it exerts weight when it is submerged. If d is less than 1.03, the buoyancy ratio is positive, and the ratio increases rapidly as d becomes smaller. For example, if d is 1 gm per cc, the buoyancy-weight ratio is 0.03; if d drops to 0.5 gm per cc, the buoyancy-weight ratio rises to 1.06.

The buoyancy-weight ratio of a material is significant because it indicates the relative ease of handling a float on the surface. A very small buoyancy-weight ratio is undesirable because it means that a great weight of float material must be used to provide the buoyancy needed. Although a large buoyancy-weight ratio is desirable, it is often not necessary.

The buoyancy-volume ratio of a float material provides a guide to its bulk and its relative ease of storing and handling. Considering only the buoyant material itself without any structure, the buoyancy-volume ratio, in pounds per cubic foot, is equal to $64.2-62.43d$, where d is density of the buoyant material in grams per cubic centimeter. Thus, to provide 1,000 lb of buoyancy, the equation shows that with a density of 0.8 gm per cc, volume would be 70 cu ft (a 4.1-ft cube), and that with a density of 0.5 gm per cc, volume would be only 30 cu ft (a 3.1-ft cube).

The buoyancy-volume ratio is also important in applications where the float moves relative to the water, since this determines the magnitude of the drag force. For example, if a float is used to support an instrument package tethered by a cable to the bottom, it is often important that the package be held vertical and at a fixed distance from the bottom. In this case the buoyancy-volume ratio must be large in order for the float to be effective in holding the cable vertical; that is, the float's vertical force must be large compared to the horizontal drag resulting from the current.

The ratio of cost to buoyancy is usually expressed in dollars per pound of buoyancy and can be calculated from the expression $Pd/(1.03-d)$, where P is the cost of the buoyant material in dollars per pound, and d its density in grams per cubic centimeter. From this equation it can be seen that a small difference in density may be more important than a large difference in material cost. For example, a material with a density of 0.6 gm per cc and costing $5 per lb will cost only $6.98 per lb of buoyancy. Selecting a material only half as expensive ($2.50) but one-third denser (0.8) will increase the cost per pound of buoyancy by 75 percent (to $8.70 per lb).

Constancy of density of a material is a factor to consider. Although not critical at or near the surface, that factor becomes important in deep water. As a material is submerged, it is exposed to decreasing water temperature and increasing pressure. This dual action causes it to contract, so that its density is greater than at the surface. At the same time the density of the water also increases, reaching a maximum as temperature approaches 39°F. If the density of the sea water increases more rapidly than that of the material, the float gains buoyancy. If the sea water density increases less rapidly than that of the material, the float loses buoyancy.

Reliability and service life are important considerations in selection of buoyancy materials. In some cases extremely high reliability is required, and premium materials must be used for corrosion resistance, with the possible result of overdesigning the float at the expense of increased weight, volume, and cost. In other cases lower reliability can be accepted to gain other advantages, such as reduced cost.

Service life is closely associated with cost. High initial cost may be cheaper for a long-lived installation than a less expensive one having shorter life. Service life is difficult to predict accurately at this time because of the unknown effects of marine organisms and other environmental factors related to the time of immersion.

A summary of important properties of float materials is given in Table 3-5. More comprehensive treatment of this subject may be found in Lippmann (1963).

Table 3-5. Important Properties of Float Materials (Lippmann, 1963)

	Material	Comments
Rigid Hollow Bodies	Steel	Inexpensive; good for depths down to about 800 feet
	Aluminum	Inexpensive; high strength-to-weight ratio underwater permits use at medium depths
	Glass	Moderate cost; high strength in compression; good corrosion resistance
	Cellular Materials	Economical; moderately efficient at shallow depths, but not as good as rigid hollow bodies at high pressures; porous materials may soak up water
Low-Density Solids	Lithium	Expensive, very low density; because of low mechanical strength and reactivity, requires supporting structure and container
	Polypropylene	Cheaper than lithium, but has higher density; very strong, tough, and corrosion resistant; can be used as a structural material
Low-Density Liquids	Hydrocarbons	Inexpensive; readily available, low-density, but subject to density changes; flammable
	Ammonia	Inexpensive; low density, changes to gas unless specially handled; slightly toxic; advantageous to use in water solution
Gases		Inexpensive, lowest density; require special mechanisms to generate underwater; need special containers and handling; difficult to store at pressures greater than 3,000 psi

PART 4
ANCHORAGE SYSTEMS

4-1. GENERAL.

Most experience in constructing deep ocean anchorages has been in connection with buoys. However, some anchorages for larger structures have been achieved that demonstrate both the advantages and limitations of current techniques and hardware. A constantly growing need exists for anchoring various types and sizes of major structures - ships, submarines, platforms - in depths to 20,000 feet. This depth is significant in that it represents 85 percent of the world's ocean-bottom areas. Deeps greater than 20,000 feet are largely in well-defined ocean trenches that are of limited scope. Nevertheless, moorings are being designed for depths as great as 30,000 feet (Devereaux, 1964).

4-2. BUOY ANCHORAGE SYSTEMS.*

Anchorages for buoys in deep ocean areas present special problems, each situation usually having a variety of factors peculiar to a given site and given requirements. Thus, generalizations on such anchorage systems must be made with care. However, certain basic principles are being followed, certain hardware is being used. These are discussed here along with existing systems and attendant developments.

4-3. Taut-Line Systems.

Two basic types of taut-line buoy anchorage systems are in use in deep ocean areas: (1) single-buoy systems, where a taut line runs from the bottom anchor to the surface or subsurface buoy (Figure 4-1; see also Chapter 3, Figures 5-6, 5-21a), and (2) two-buoy systems, where a taut line runs from bottom anchor to a subsurface buoy which, in turn, is joined by a pendant line to the surface or another subsurface buoy (Figure 4-2).

The anchor or bottom implement by which the system is attached to the bottom and maintained on station may, in either case, be a conventional-type anchor, arranged singly or in clumps, or in combination of clumps and single implements. The clumps or deadweight element can be steel cubes, railroad wheels, rail sections, concrete-filled drums, concrete blocks or other similar constructions. Conventional anchors can be special concrete shapes or steel with flukes that embed in the bottom under horizontally applied loads. These are discussed in part 3. See Appendix C for a design procedure for a taut-line mooring system for buoys.

4-4. Single-Buoy Systems. Single-buoy taut-line systems (Figure 4-1) commonly use a surface float, a line of good elastic properties, appropriate fittings, and one or more anchors. The elasticity of the line tends to allow it to generate its own scope in absorbing wave-induced surges. Swivels are needed at strategic intervals in a line (depending on its size and type) to dampen the effects of torque caused by rotation of the surface buoy. Ground tackle is generally chain. A weak link or acoustically actuated explosive device provides a means to separate retrievable from nonretrievable gear. Lines used in this system are usually of the synthetic type such as nylon or polypropylene. Nylon is preferred as it will stretch and its elasticity remains good for about one year.

An example of the single-buoy taut-line anchorage system is a series of 106 anchored buoy stations used for recording deep ocean currents along a line from Cape Cod, Massachusetts, to Bermuda (Richardson, 1963). The stations were set between December 1960 and April 1963 in various depths to 18,000 feet by scientists of the Woods Hole Oceanographic Institution. The configuration of the anchorage system used is shown in Figure 4-1. A toroidally shaped

*A suggested list of specification items for designers is presented in Appendix D.

surface buoy, 8 feet OD by 3 feet ID supported the required navigational signals on a 10-foot tower. Underneath the buoy was a 6-1/2-foot bridle joined to a 20-foot chain leader, which in turn connected with a 164-foot length of 9/16-inch-diameter polypropylene mooring line. To this was attached a current meter. Subsequent current meters were separated by 1,640-foot lengths of 9/16-inch-diameter polypropylene line, the last length of mooring line ending at a 4-inch pear-shaped sling ring. To this ring was fastened 20 feet of 1-inch-diameter polypropylene rope to supply buoyancy to the weak link. The chain comprising part of the ground tackle consisted of 500 pounds of 1/2-inch chain, a clump weighing 800 pounds, and a 90-pound Danforth anchor. Later anchorings were made with a new type of anchor that tended to bury itself in the bottom to minimize drag (see Stimson anchor, paragraph 3-8).

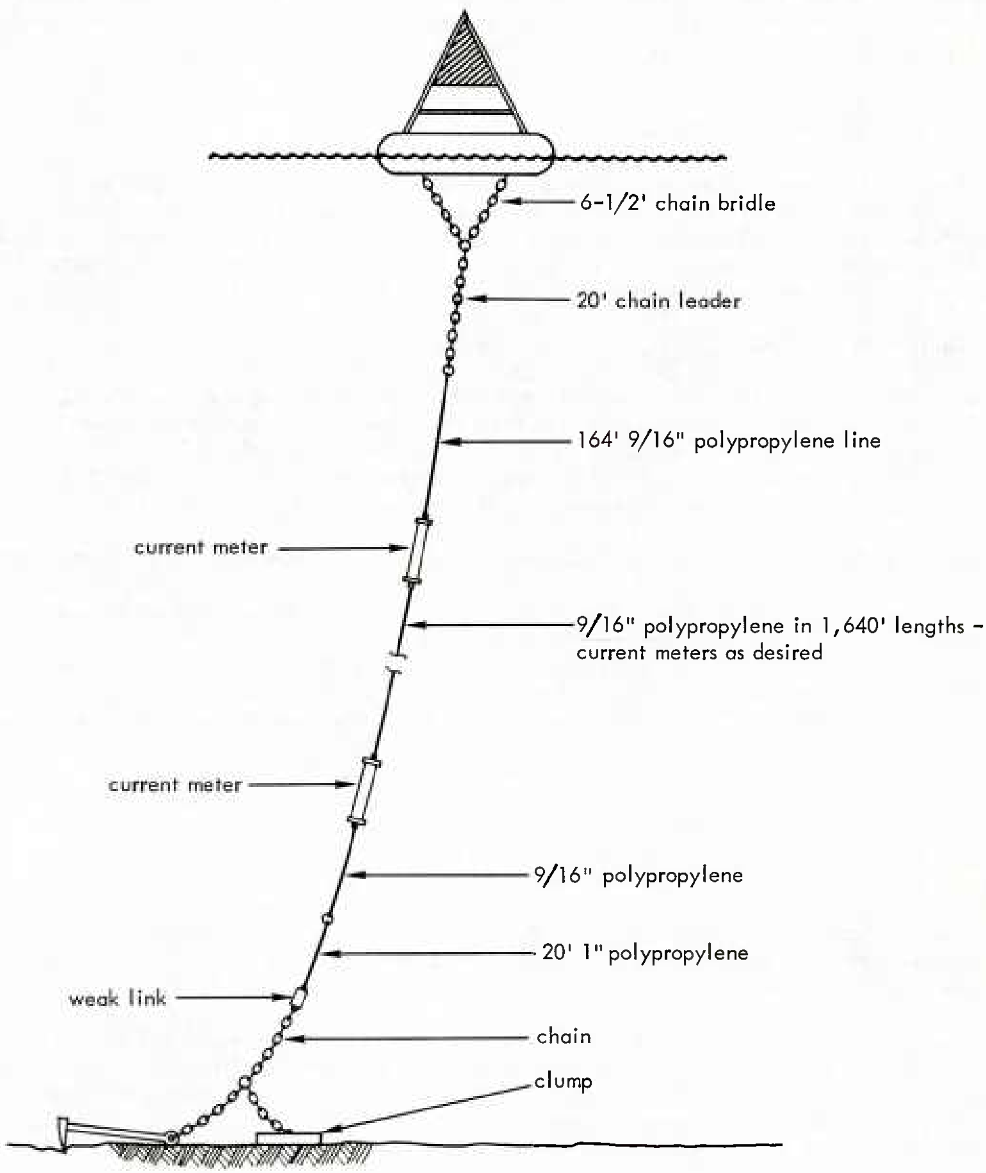


Figure 4-1. Single-buoy taut-line anchorage system.

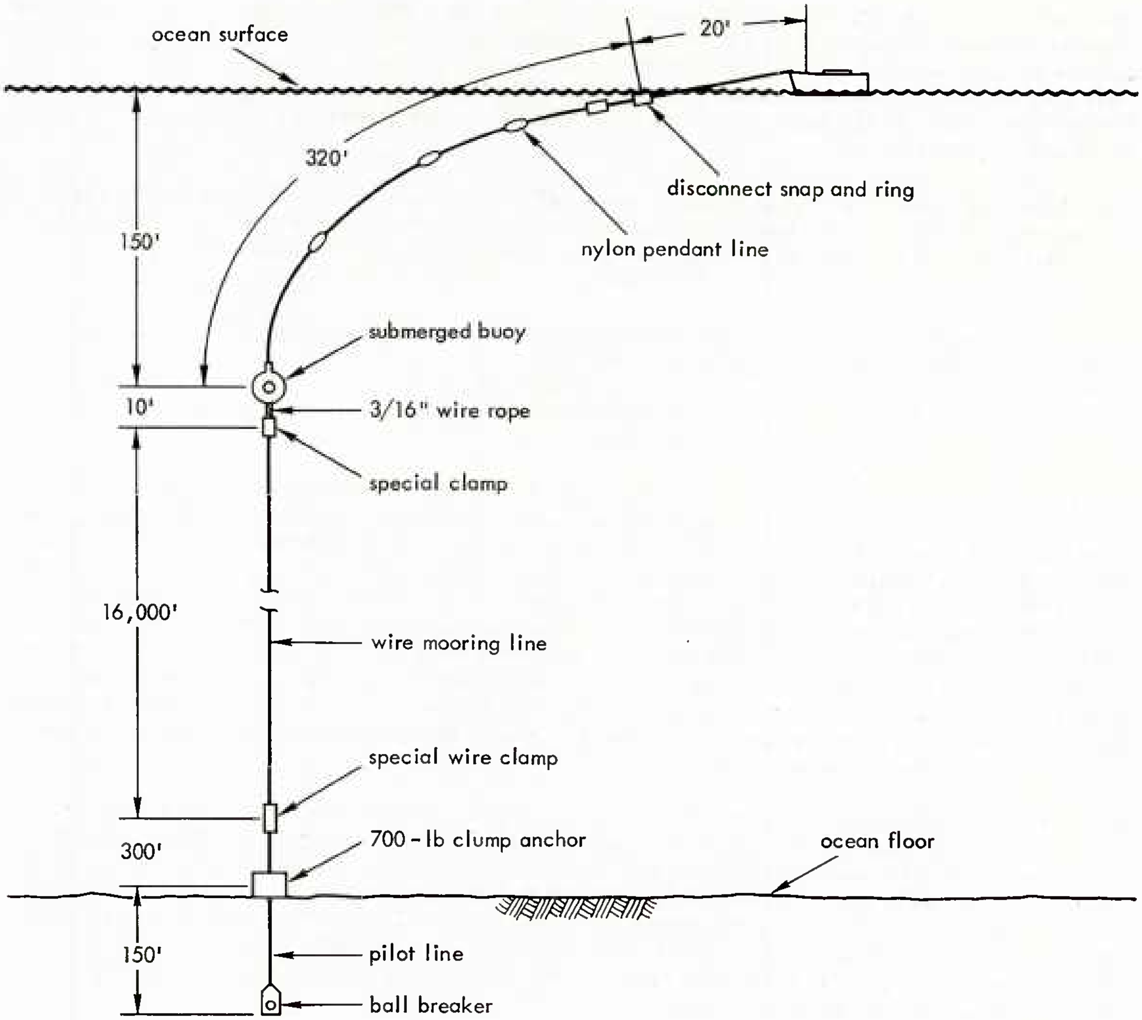


Figure 4-2. Two-buoy taut-line anchorage system.

The life span of individual stations varied. Failure of all or parts of the majority of the stations occurred within the first 90 days. One buoy station was recovered intact after 233 days. At stations where strong currents were measured (3 to 4 knots) the buoy systems had a life of only a few days. Failure was attributed to the fact that polypropylene rope creeps under high stress (more than half of rated break strength). Of 50 deep systems set (water depth greater than 1,600 feet), 37 were recovered essentially complete. Of the losses, 6 were due to unknown causes, and 3 to cordage failure probably attributable to fishbite. Of 14 deep water stations set in the Gulf Stream, 6 were lost from unknown causes.

A taut-line buoy anchorage system (Figure 4-3) that does not use a subsurface float was designed by scientists at Scripps Institution of Oceanography (Isaacs, 1963). This system is comprised essentially of a two-hull catamaran surface buoy, a 3/8-inch nylon line with about 17 percent stretch, and a deadweight bottom implement weighing 1,200 pounds, constructed of railroad rails welded together. A 150-foot length of 3/8-inch galvanized chain connects the nylon line to the anchor. The nylon line is attached to the underside of the buoy near midships in a manner that makes theft or retrieval by unauthorized persons difficult. The catamaran affords a large flat stable deck that facilitates servicing and repair. Its unorthodox construction also makes it unattractive for theft. The entire buoy anchorage system has the further advantage of eliminating the surface pendant line with attendant problems of fouling by ships and impact loadings.

Use of the taut nylon line requires that it have sufficient elasticity to withstand wave-induced excursions of the buoy. Scripps' experience indicates that the nylon retains its elasticity for at least 1 year and exhibits no measurable creep or shrinkage after installation. Two prototypes of this design have been successfully emplaced at 1,800 feet.

4-5. Two-buoy Systems. Two-buoy taut-line systems, as illustrated in Figure 4-2, usually comprise a surface float, pendant line, subsurface buoy, taut line and ground tackle, and anchors. The surface buoy can be one of several types, surface-following, tow-under or stable long-period spar. In general, it should be large enough to support the entire anchorage system in the event the subsurface float fails.

The pendant line (sometimes referred to as a painter) leading from the surface buoy to the subsurface buoy should be buoyant or have buoyancy provided to eliminate sag and entanglement with the riser line. This line is subject to the greatest wear due to sudden periods of tension and slack. It is usually composed of synthetic materials or wire cable. For some installations it may be necessary for the pendant to rise vertically to the surface float, in which case it should be highly elastic in order to absorb shock loads resulting from wave action on the surface float. The subsurface float provides sufficient buoyancy to support the riser line and apply tension to the anchor. This float tends to maintain a position directly above the anchor point on the bottom. Forces tending to move it from this position are due to current action on the riser line, on its own surface, and those relayed by the pendant line as a result of wave action and wind on the surface float.

Subsurface floats commonly used are of two basic types: pressurized metal vessels in the form of tanks or spheres, and similar vessels filled with low-density foam. The submerged types must have pressure approaching that of ambient sea at the intended depth. Subsurface floats are commonly placed at depths between 50 and 150 feet. Criteria for positioning them are generally as follows: (1) deep enough to escape ship traffic; (2) deep enough to minimize effects of surface waves; (3) deep enough to escape surface currents (below thermocline); (4) at the greatest depth at which observations are desired; (5) at depths divers can reach; (6) deep enough to escape surface fouling.

The mooring line of a taut-line two-buoy system must be strong enough to withstand the constant tension induced by the buoyancy of the submerged float. If wire rope is used it must be strong enough to sustain its own weight under deep ocean conditions plus providing working load strength. If synthetic lines are used, their elasticity requires an accurate estimate of the proposed operating depth, so that proper length of line between anchor unit and submerged buoy can compensate for the approximate 15 percent stretch of fiber line and thus maintain proper tension. A self-operating submerged reel or winch can accomplish the same results (see paragraph 7-4). Synthetic lines are easier to handle on shipboard due to their light weight and flexibility. Ground tackle, similar to that of a single-buoy system, generally has a clump anchor with remotely controlled release device or a weak link and an anchor chain parallel to the ocean floor leading to one of several types of anchors. Anchors prevent drift of system resulting from undersurface currents and other forces.

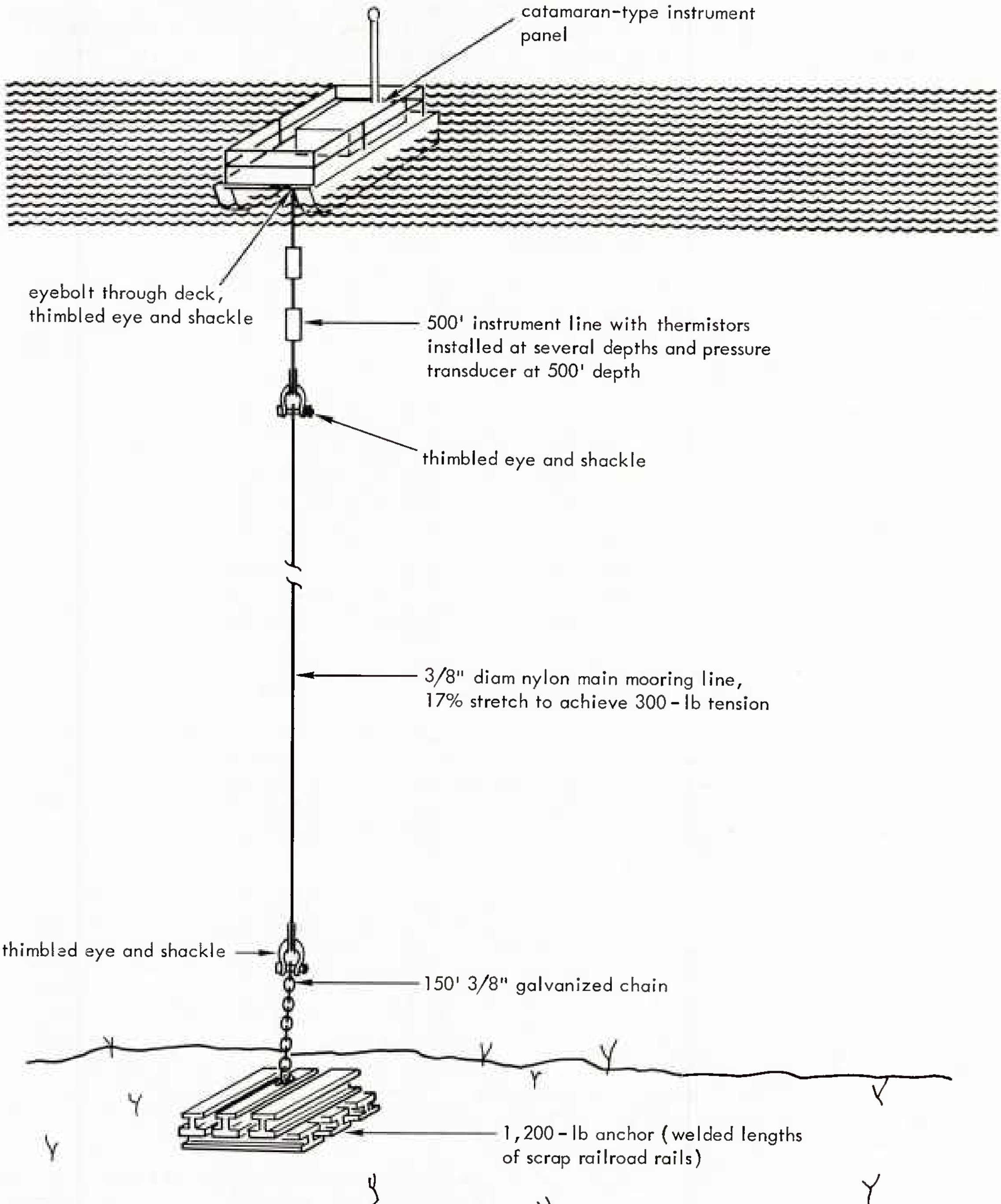


Figure 4-3. Taut-line buoy anchorage system - Scripps.

An example of the two-buoy taut-line anchorage system is one designed and used by the Scripps Institution of Oceanography (Isaacs, 1963). Major components (Figure 4-2) were skiff-type surface float, a 36-inch-diameter steel-sphere submerged buoy pressurized to ambient sea pressure at 150-foot depth, and a 700-pound clump-type anchor. A 20-foot length of nylon line connected the skiff to a disconnect (snap and ring). A nylon rope 320 feet in length was attached between the disconnect and the submerged buoy. From the submerged buoy, 10 feet of 3/16-inch-diameter wire rope connected to a special wire clamp. From this clamp the main mooring cable led down to a second special wire-rope clamp, from which 300 feet of 3/16-inch wire rope led to the anchor. Below the anchor a ball breaker unit was attached by 150 feet of manila line. The purpose of the ball breaker was to send an audible signal to the surface to indicate when the anchor approached the bottom. This was necessary so that the winch lowering the anchorage could be stopped and then operated more slowly to prevent kinkage of the rope when the bottom was reached. Special wire-rope clamps were required to electrically insulate the mooring wire clamp from the shackle and connecting wire.

4-6. Slack-Line Systems.

Slack-line anchorages used for buoys and other minor surface structures requiring relatively long-term, firm stationing are commonly characterized by: (1) a conventional bottom anchor; (2) a length of heavy chain, shackled to this anchor and lying on the bottom; (3) a length of lighter weight chain or a second anchor attached to the heavy chain; (4) a cable of low density rising to the surface; (5) a connecting cable and/or chain near the surface attached to the surface buoy or structure. The conventional anchor provides holding power that maintains the bottom position of the system. The heavy chain and/or second anchor acts as weight to prevent uplift on the primary anchor. The lighter chain and the low-density riser cable absorb shock forces induced by movements of the structure on the surface. The riser cable generally is polypropylene, which is slightly buoyant. Therefore, none of its strength is used in supporting its own weight. Also, its elasticity is valuable in absorbing surges and shocks. The weight of the anchor chain, and of the second anchor, if used, plus, on occasion, the weight of the primary anchor, probably contribute to the holding force.

It is unlikely that the system as described applies a horizontal force on the primary anchor sufficient to cause embedment of the anchor to a material extent. However, the system has proved successful in several installations. The combination of features on the ocean bottom serves as factors of safety against movement. The system appears usable until a reliable small anchor, capable of being easily and accurately placed, and possessing high capacity to resist uplift forces, is operational.

An example of a slack-line anchorage system for buoys is the NOMAD (Navy Oceanographic Meteorological Automatic Device), shown in Figure 4-4. This system, designed at Woods Hole Oceanographic Institution, has been anchored successfully in 10,800 feet of water in the Gulf of Mexico since 1959 (Corwin, 1959). Its basic elements consist of a "NOMAD" skiff-type surface buoy, 10,000 feet of 3/4-inch polypropylene line, and a 500-pound mushroom anchor. In detail, the skiff has a yoke attached to the keel which holds one end of a 100-foot length of 3/4-inch chain, the other end being joined to 5,000 feet of 3/4-inch dacron line by a thimble eye and shackle. The dacron line in turn is attached to the 10,000 feet of polypropylene by another thimble eye and shackle. The lower end of the polypropylene line is attached to 222 feet of 3/4-inch chain to which is attached a length of 1-1/4-inch chain holding the mushroom anchor.

Utilization of two types of line, polypropylene and dacron, accomplishes two things. The heavier-than-water dacron plus the chain assure that no portion of the polypropylene cable will rise to the surface as the skiff changes position during slack loading. Also, the "S" shape formed by the two lines tends to reduce surface excursion and absorb shock forces in turbulent conditions.

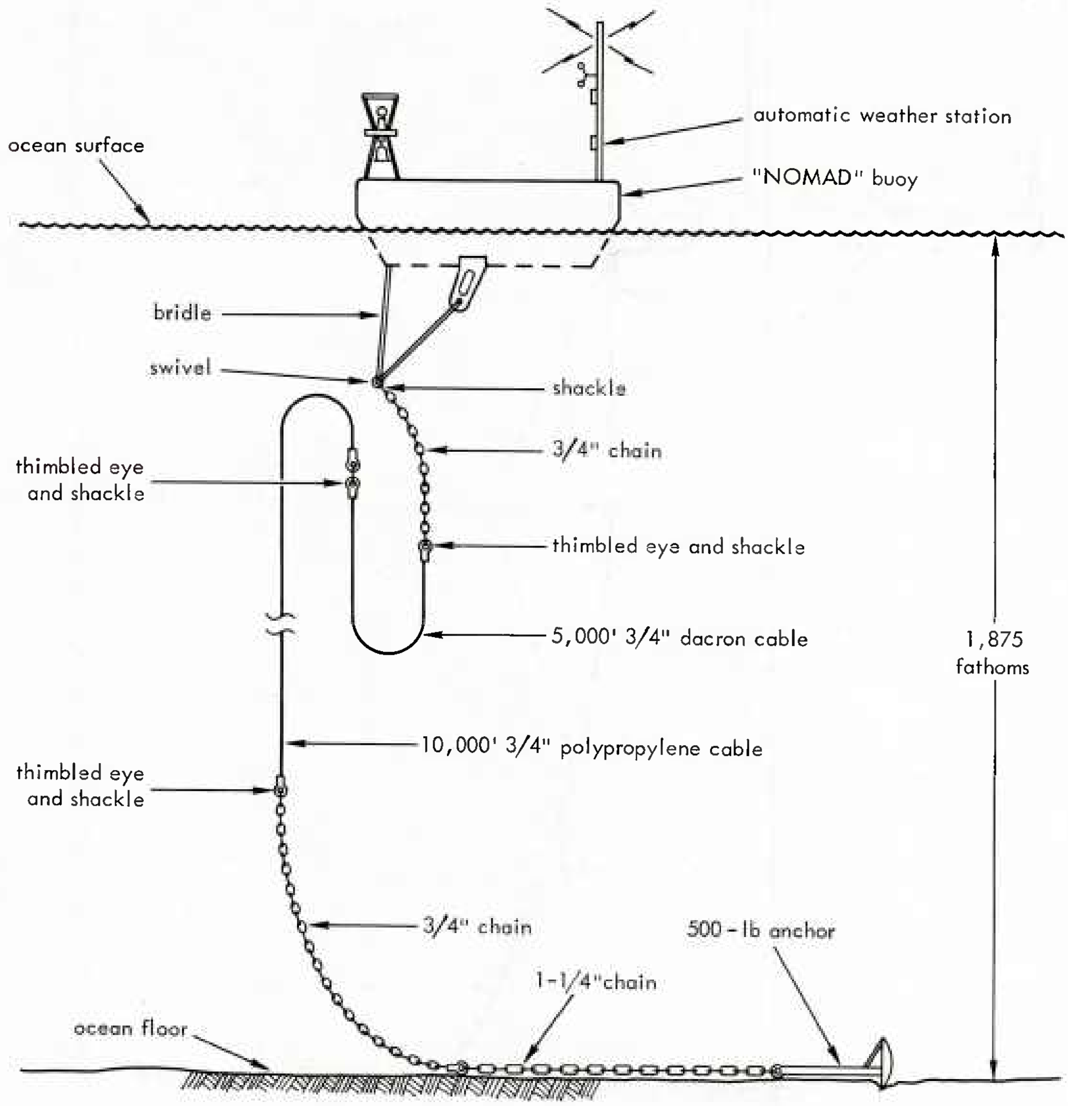


Figure 4-4. Slack-line anchorage system for buoy - NOMAD.

Another example of a successful slack-line anchorage system is shown in Figure 4-5. This system was designed for Project DOMINIC by the San Diego Naval Repair Facility (Huntly, 1963). Fifteen 25-ton pontoon barges had to be maintained on station in depths of 12,000 to 18,000 feet. Each barge was attached to three 17-inch spherical steel buoys connected to each other by 3/8-inch welded chain. The spherical buoys were connected to a 3/4-inch polypropylene line leading down to a drogue anchor, to which was connected a 45-foot length of 3/4-inch chain with two 1,000 pound LWT anchors on the bottom.

The polypropylene line was in lengths of 2,400 feet, each length connected by 3/4-inch teardrop thimbles and a Miller swivel. The Miller swivels were used to minimize rotation in the line during placement and while in service. The purpose of the drogue anchor was to slow the descent of the LWT anchors during installation of each anchorage, which required about 1-1/2 hours to complete.

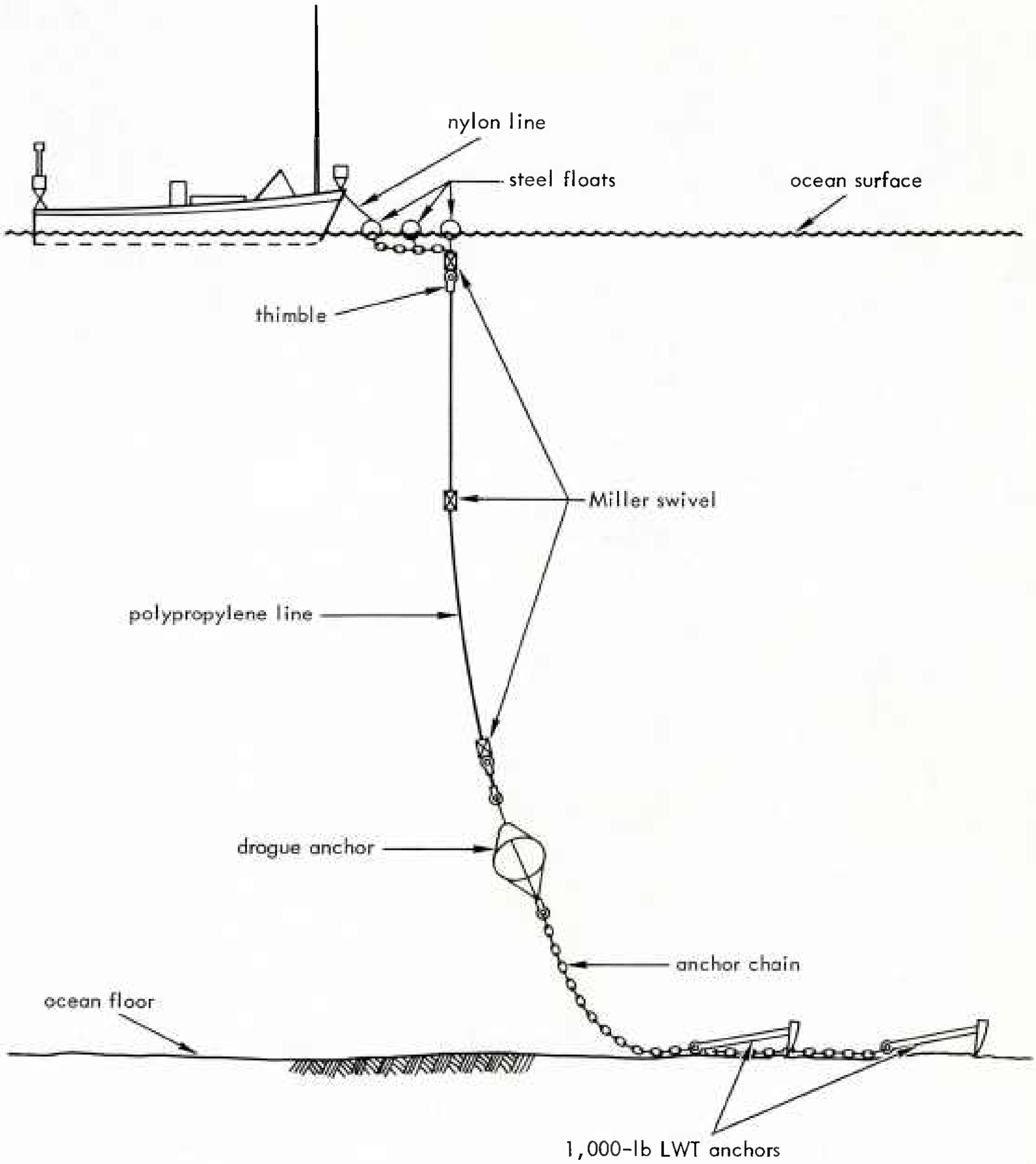


Figure 4-5. Slack-line anchorage system for buoy - DOMINIC.

These anchorage systems were completely successful for the purpose designed. The installations were in place approximately 8 months, during which time no failures occurred. Subsequently, at least one barge is believed to have been on station an additional 18 months without maintenance or repair.

Since early 1964, a slack-line system has been used to maintain a large manned buoy on station in about 7,200 feet of water in the Mediterranean Sea (Figure 4-6), according to Richards (1964). It is continuously manned by a crew of four from the International Institution of Oceanography of Monaco under direction of Commander J. Y. Cousteau. The bulk of the mooring cable is composed of polypropylene rope with wire rope used near the surface and at the bottom. The buoy swings in a radius of about 3 miles at the surface around the position of the anchor. The anchor is a conventional type designed to embed itself in the bottom when subjected to a horizontal force component.

The buoy is about 225 feet long with an average diameter of 6. 6 feet. Ballast in excess of 100 tons is used to stabilize it. Waves as high as 16 feet have little effect on stability. About 32 feet of the buoy is above the surface. This portion contains living quarters and a helicopter landing platform on top. Compartments for laboratories are located in the submerged portion of the tube, these having viewing ports to a depth of 165 feet.

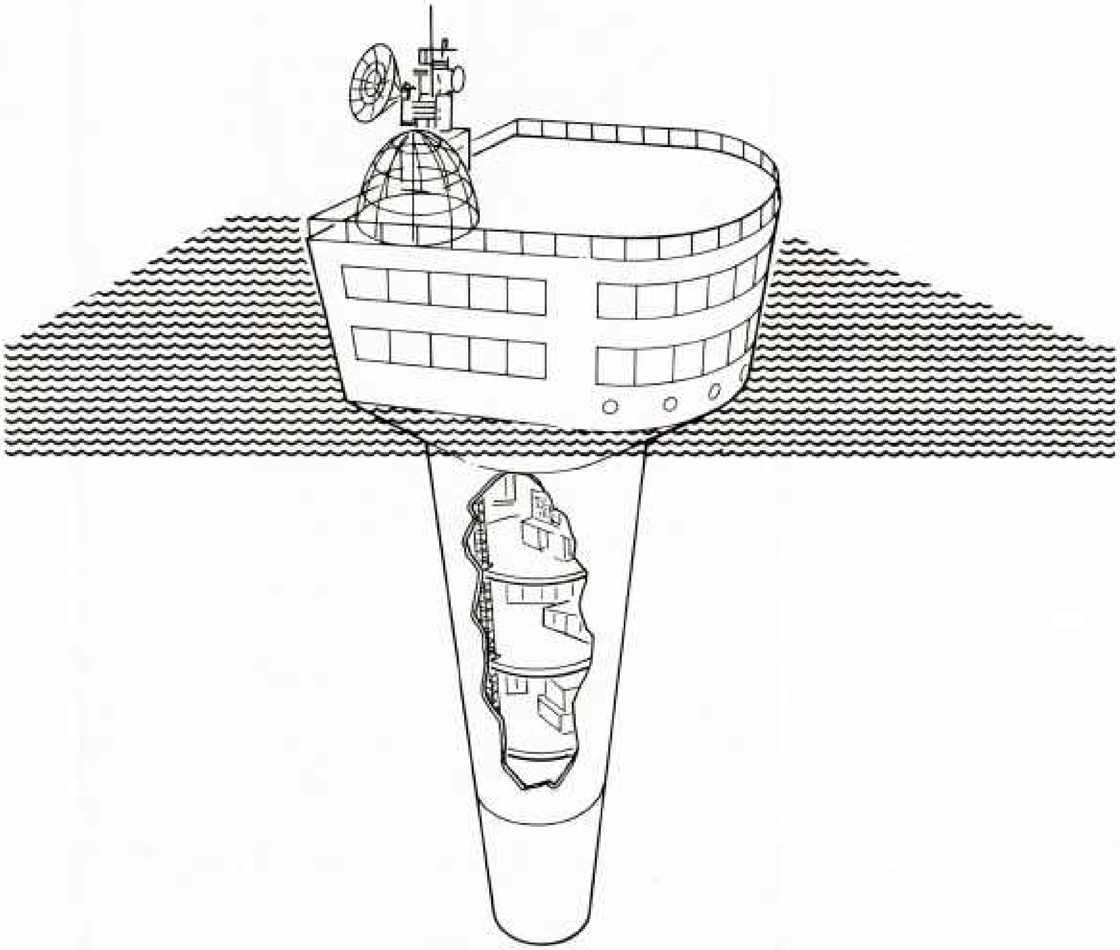


Figure 4-6. Manned French research buoy illustrates magnitude of buoy structures being anchored in deep ocean areas.

4-7. Multileg Systems.

In addition to the single-leg taut-line and slack-line buoy anchorage systems, a variety of systems has been developed with a multileg arrangement. Major components are the same as in the single-leg systems: surface and subsurface buoys, anchors and tackle gear. Two basic configurations have generally been used. In the first, each leg of the system rises directly to a subsurface buoy similar to the taut-line single-leg system, and from the subsurface buoys pendant lines lead to a central or main buoy. In the second, each leg leads on a slope directly to a central buoy which may be submerged or on the surface; buoyancy is provided in the cable lines to overcome their weight and negate the catenary effect; if the central buoy is submerged, a surface buoy is attached to it by a riser line to serve as a marker.

Some advantages of multileg anchorage systems are a probable decrease in surface excursion, availability of ample clear space for suspension of instruments, and retrievability of other parts of the system in case of failure of one part resulting from loss of one leg line. Included among the disadvantages are the complexity of positioning anchors and buoys for optimum functioning; potential need for more than one vessel to effectively place components; need for more buoys and ground tackle, more weight-and-gear handling equipment on board surface vessels than for other anchoring systems, with consequent increase in stowage and other logistical requirements; more protection and maintenance problems because of increase in number of lines and buoys; and greater cost and expense due to the preceding considerations.

An example of an operative multileg buoy anchorage system is one installed at 1,800-foot depths off Santa Barbara, California (Daubin, 1964b). It is comprised of two separated submerged-buoy taut-line moorings, each connected by wire rope pendants to a surface buoy carrying power supplies and instruments. Details are shown in Figure 4-7. The surface buoy is an octagon-shaped fiber-glass hull filled with foam plastic. It is 8 feet 6 inches across and 2 feet 3-1/2 inches high (not including superstructure). The subsurface buoys are steel cylinders, 5 feet in diameter with wall thickness of 1/4 inch. They are pressurized to about 50 psi in excess of ambient sea pressure at 120 feet and have a buoyancy of about 4,000 pounds. The bottom implements consist of 13 iron disks weighing 6,000 pounds and connected to two 80-pound Danforth anchors by 50 feet of chain.

It is claimed that excursion of the submerged buoys is about 19 feet in normal conditions and 34 feet in storms that result in conditions of Beaufort scale 6. The surface buoy is constrained within these limits by the tautness of the lines to the submerged buoys. Each pendant line has three intermediate floats to negate the weight of wire suspended between the submerged buoys and the surface buoy.

Advantages claimed for this design are instrument stability in submerged conditions; reduction of tendency in cables to loop or kink; reduction of kinetic energy from wave action in surface buoy; protection against loss of surface buoy as result of failure of one anchor element with consequent difficulty in retrieving other end; elimination of fouling between mooring lines and instrumented lines when latter are lowered below surface buoy; and greater permanency than other similar installations.

Disadvantages are listed as necessity for relatively large quantity of wire and subsurface elements; relatively greater cost and difficulty of installation; and greater water drag due to action of current on wire rope span.

A further example of a multileg buoy anchorage is one installed by the U.S. Coast and Geodetic Survey in 4,200 feet of water off the coast of Santa Catalina Island, California (Aldredge, 1964). The purpose of this anchorage was to position a stable instrument platform 100 feet below the surface to obtain precise scientific measurements relating to magnetic fields. The configuration and major features of this system are shown in Figure 4-8. It is a three-legged anchorage system comprised basically of the submerged platform and an assemblage of cables and anchors to maintain position of the platform. The platform consists of a toroidal float with an outside diameter of 8 feet 8 inches and a cross-section diameter of 21 inches attached to a triangular aluminum-alloy frame. The float has a rigid case of 3/8-inch fiber glass impregnated with a polyester resin. Its core is a low-density polyurethane foam. The float weighs 552 pounds in air and has a buoyancy of 2,517 pounds. The 95-pound frame is a weldment of 6061-T6 aluminum alloy. The float is held on station by three equally spaced cables about 8,000 feet long leading down to the anchor assemblies. The anchor assemblies consist of two 55-gallon steel drums filled with concrete and chained to a 65-pound Danforth anchor. The cables are under a tension of about 1,000 pounds and make an angle of approximately 45 degrees with the horizontal. To prevent the formation of large catenaries, the cables are buoyed at regular intervals by glass spheres. The cables are 1/4-inch galvanized steel for all but the 80 feet nearest the submerged buoy. This section is 3/8-inch phosphor bronze, and serves to keep the hazard of magnetism in the steel cables a good distance from the instruments on the platform.

The installation was set in place by first lowering the anchors of two of the legs to their approximate position on the bottom, with each anchor aligned about 120 degrees from the other two. After necessary connection of lines and fittings to one another and to the buoy were made, the third anchor was lowered to its approximate position. Then by means of a crown line attached to the service vessel on the surface, the third anchor was dragged along a radial line outward from the center of the anchorage configuration until the buoy was submerged to a depth of 70 feet.

4-8. MAJOR-STRUCTURES ANCHORAGE SYSTEMS.

Major-structures anchorage systems are here classified as those designed for structures generally in excess of 10-tons' displacement. Achieved installations in this range include anchorage of large surface vessels in depths to 20,000 feet (Holm, 1964), construction of a three-point moor for ships to cruiser size in a depth of 5,500 feet, and construction of a large bottom-rest structure in a depth of about 220 feet.

4-9. Achieved Systems.

Achieved major-structures anchorage systems are mostly limited to conventional designs and gear, with modifications and adaptations for each application. Such anchorages have been placed at depths to 20,000 feet. They can be conveniently classified as single-leg flexible, multileg flexible, and bottom-rest. The term "flexible" is used to distinguish anchorages employing the principle of flexible restraint from those employing restraint or support from a fixed position or bottom-rest.

4-10. Single-Leg Flexible Systems. Single-leg systems are the least complex. The general configuration is typical of that shown for the anchoring of the USNS JOSIAH W. GIBBS (Figure 4-9). Basically, this consists of an anchor or anchors on the bottom and a slack riser line leading to a structure on the surface. The anchors are conventional types designed to resist primarily horizontal loads. A weak link is usually incorporated in the line above the anchor to permit retrieval of most of the line in case of snagging of the anchor. A length of chain is usually placed in the line next to the anchor because of its resistance to abrasion, wear, and damage from contact with the bottom. The chain also acts as a weight to minimize the vertical force component on the anchor. In addition to the chain, a sinker is sometimes attached to the line to further reduce the vertical force component.

The connecting line leading from the anchor to the surface may be wire-rope cable or any of several synthetic materials such as dacron, polypropylene, or nylon. Both tapered- and uniform-diameter wire-rope cables have been used. Use of a tapered cable reduces cable weight, thus permitting more of the cable strength to be applied to net holding power. The disadvantage is that operational and handling problems during placement and retrieval are intensified; also, a greater inventory of rope sizes is required. The synthetic ropes need not be tapered because they are buoyant, or nearly so.

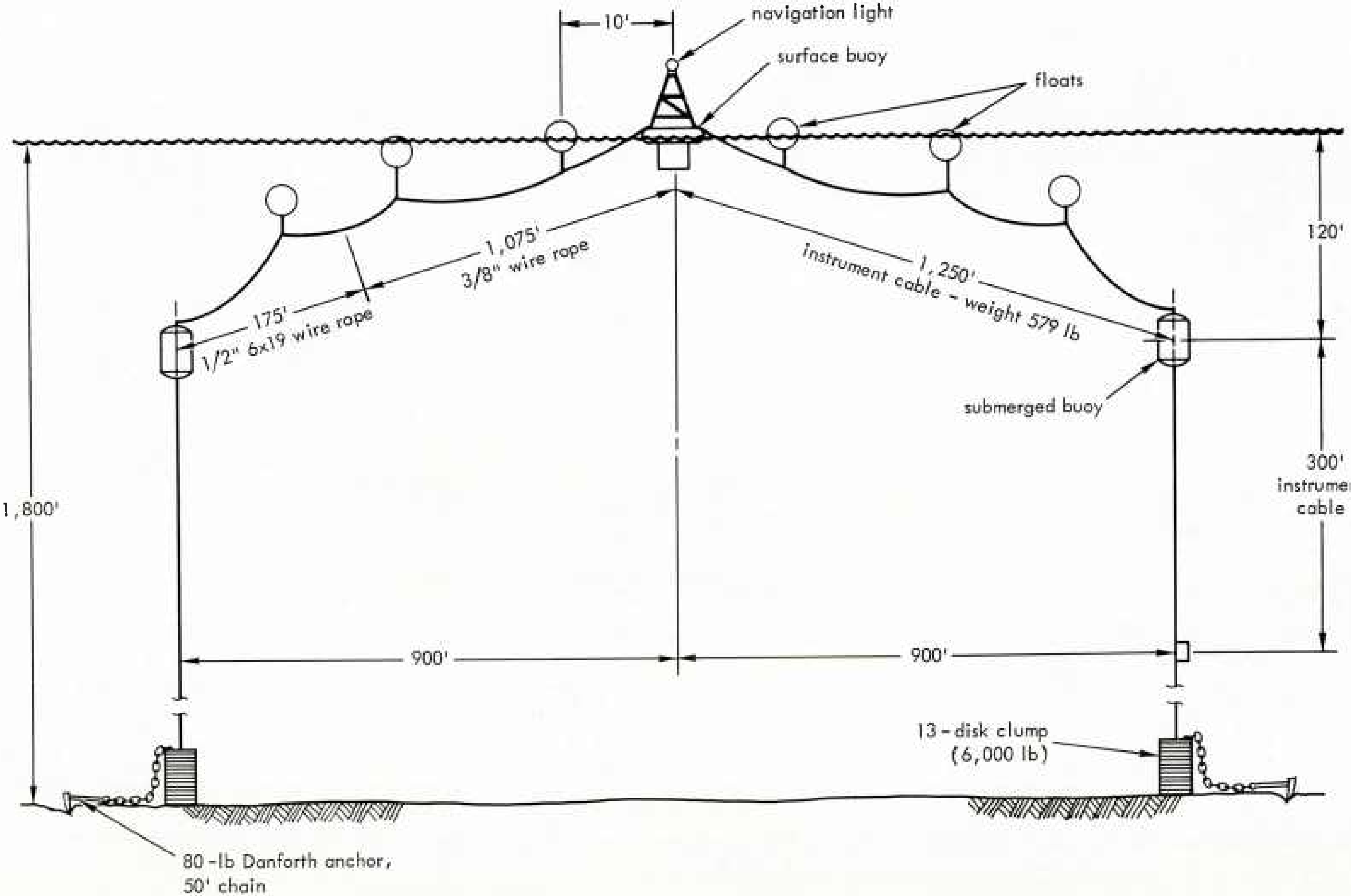


Figure 4-7. Multileg buoy anchorage system.

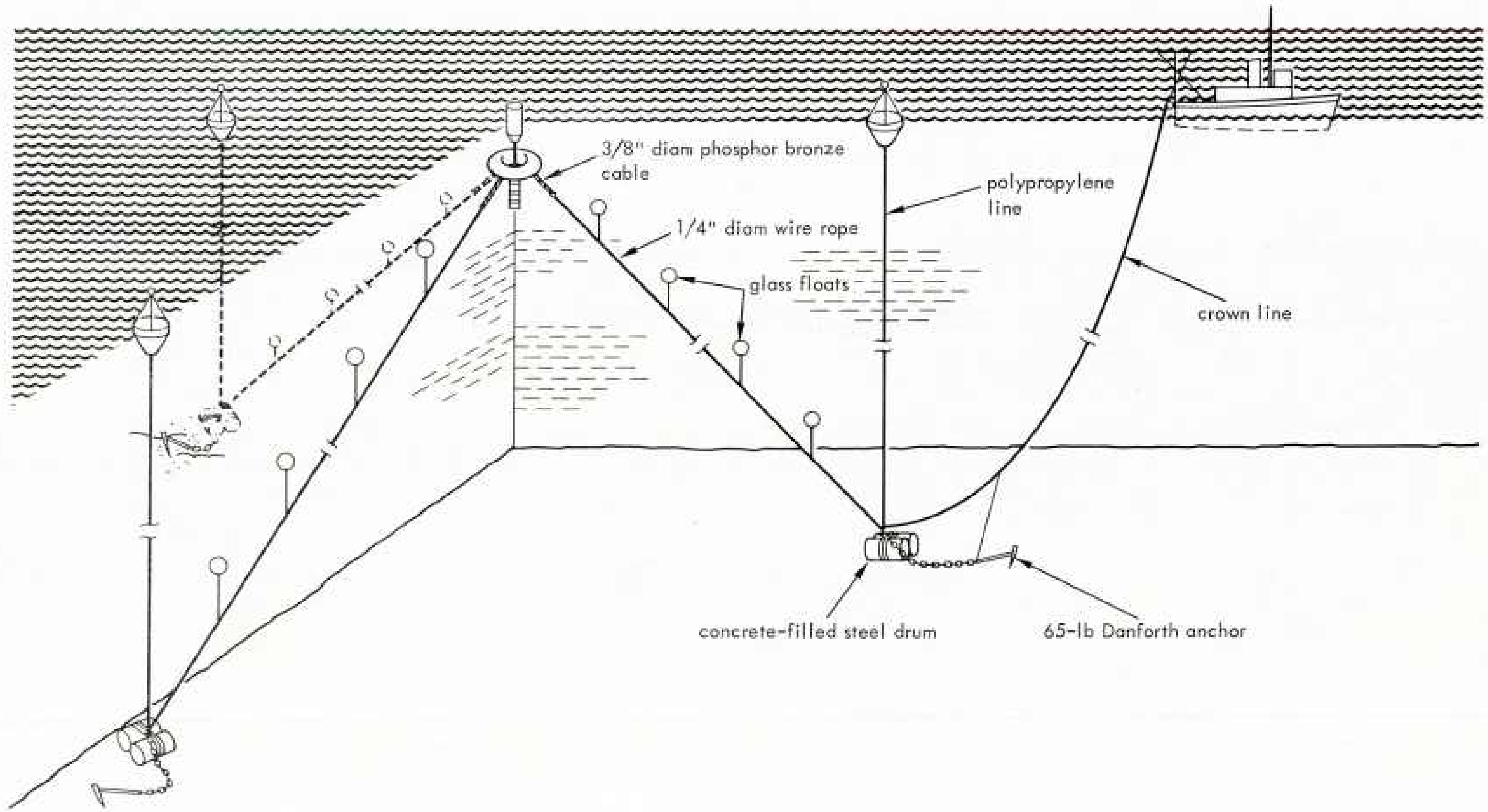


Figure 4-8. Deep-sea stabilized platform.

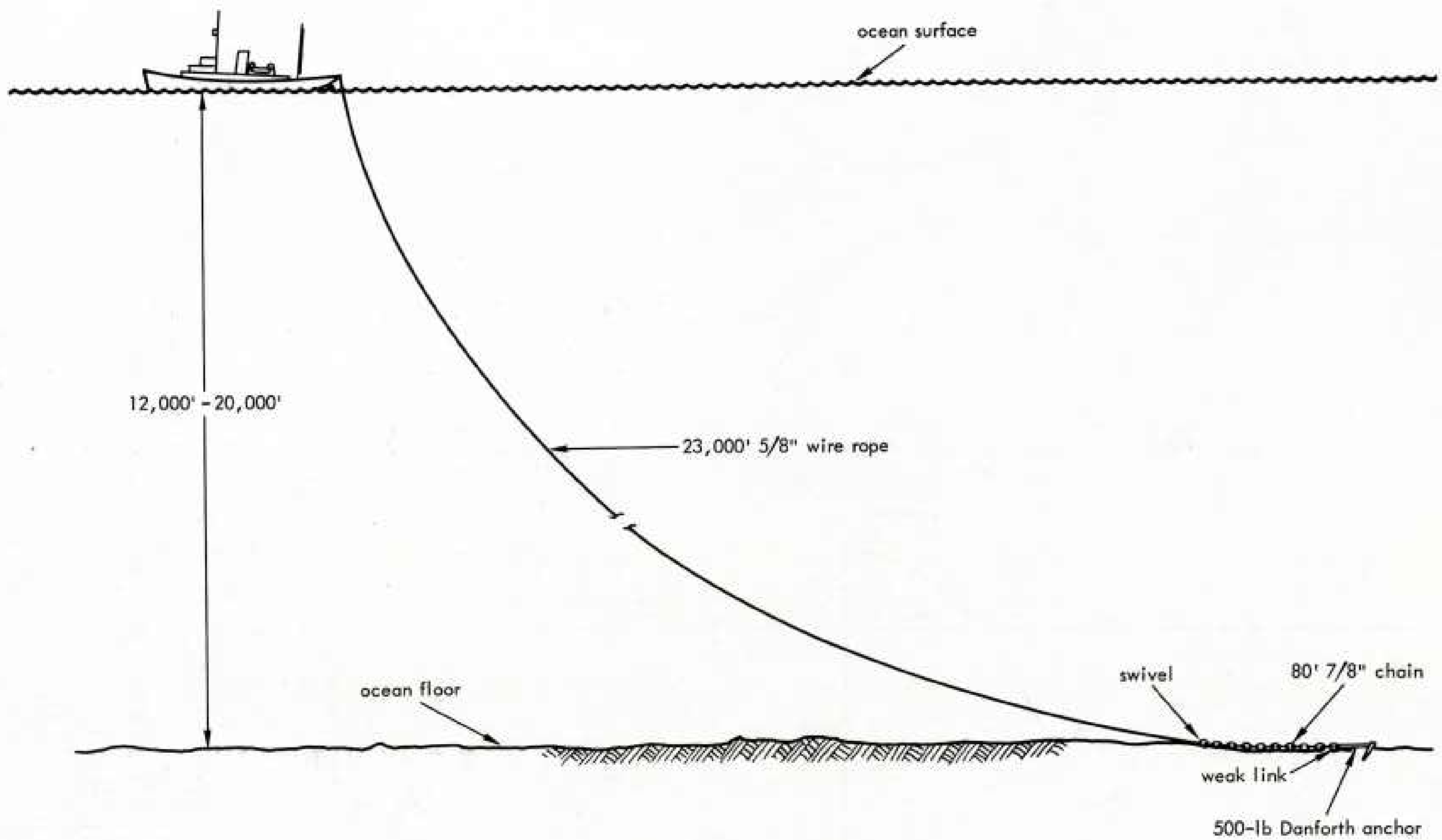


Figure 4-9. Single-leg anchorage system for USNS JOSIAH W. GIBBS.

The single-leg flexible anchorage system is useful in deep ocean applications to maintain ships and other surface vessels in a general vicinity for relatively short periods of time. Surface excursion necessarily is correlated with the scope of line needed to maintain the horizontal component on the anchor. It can amount to radial distances about a point over the anchor of approximately 1.3 times the depth. Holding capacities of 30,000 to 50,000-pound line tensions probably can be developed with conventional drag-type anchors. These capacities are sufficient to hold 6,000-ton vessels in position in 30-knot winds.

Most experience in single-leg flexible anchorage systems has been related to anchoring ships in deep water. These anchorings date back at least as far as 1888-1889 when the U.S. Coast and Geodetic Survey steamer BLAKE, under the command of J. E. Pillsbury, carried out studies of the Gulf Stream. The BLAKE was anchored at several locations in depths to 13,000 feet (Isaacs, 1963). Numerous anchorings by other vessels have been accomplished and recorded since then. Some vessels have been anchored in depths greater than 15,000 feet for periods up to two weeks. The METEOR was anchored in 18,000 feet for two days (Isaacs, 1963). According to Sysoyev (1957), the VITIAZ, a 5,546-ton Russian research vessel, was anchored for many hours at depths up to 31,000 feet under a variety of conditions. The anchorings cited and others have been for relatively short periods of time and do not approach permanency, capacity, degrees of fixity on station, and reliability necessary for the many constructions contemplated.

A more recent single-leg flexible anchorage is reported by Holm (1964). This system is designed to anchor the 17,000-ton vessel MISSION CAPISTRANO in 20,000 feet of water, so that position can be held indefinitely. It uses a 3,000-pound anchor and a polypropylene line.

Another recent experience in anchoring a vessel in deep water is that of the aforementioned USNS JOSIAH W. GIBBS. Since 1961, a series of 24 anchorings of this 2,800-ton vessel have been accomplished by the Hudson Laboratories of Columbia University (Beck, 1962). She was anchored in depths to 18,000 feet and maintained on station without discernible drift in winds to 37 knots. Whereas most earlier anchorings were probably accomplished by methods based on experience, the anchorings of the GIBBS were based on mathematical analyses. Consequently, information from these anchorings is particularly pertinent to single-leg flexible system design. The GIBBS anchorage system consisted of a 500-pound Danforth anchor, 80 feet of 7/8-inch anchor chain, a weak link and a 5/8-inch-diameter wire rope rising to the GIBBS (Figure 4-9). The weak links used in the different anchorings varied in strength from 18,000 pounds in depths of water less than 12,500 feet to 13,600 pounds in depths of water over 17,500 feet. The cable used was 6 by 19 galvanized plow steel with wire rope core.

4-11. Multileg Flexible Systems. Barring major technical breakthroughs, structures such as ships, submarines, and large surface or submerged ocean stations will require anchorage systems that utilize two or more legs to achieve desired permanency and station-keeping objectives. A multileg flexible anchorage system even in shallow water is a complex construction that requires large amounts of tackle, gear, connections, and other furnishings. The complexity, the materials required, and the problems of installation increase at a geometric rate with depth. Current thinking is that the maximum depth at which it is practicable to construct a permanent type multileg anchorage is about 500 feet. Nevertheless, multileg anchorages have been constructed at greater depths. Five significant multileg systems have been achieved, according to Hydrospace (1964): moors for Operation Hardtack, TOTO I moor, mooring of the SQUAW, mooring for the ARTEMIS installation vessel, and TOTO II moor.

Perhaps the most significant of these five is the TOTO II, designed and installed under the jurisdiction of the U.S. Naval Bureau of Ships in the Tongue of the Ocean near the Bahama Islands. After an earlier anchorage had collapsed, TOTO II was successfully constructed in the spring of 1962, at a depth of 5,500 feet. As shown in Figures 4-10 and 4-11, it is comprised of three wire-rope legs and a complex of seven buoys on the surface. Each leg is oriented 120 degrees from the others and rises in a double catenary configuration from a 6,000-pound LWT anchor and four shots (360 feet) of 2-1/2-inch chain on the bottom (Figure 4-10) to a point about 100 feet below a main buoy which supports and terminates the upper end of the leg. From this point a 2,500-foot span wire rope under 1,000-pound tension runs beneath the surface and connects to the anchorage center which is supported by another buoy. Each leg is supported in its double catenary by an intermediate buoy connected to it by a riser pendant.

All wire-rope components except the buoy riser pendants are 1-1/4-inch, 6 by 19 filler wire, extra-improved plow steel, galvanized with independent wire strand core. The buoy riser pendants are 1-5/8-inch, 6 by 19 IWRL galvanized. All buoys are filled with unicellular plastic which renders them practically impermeable to penetration by water. The center and main buoys are 15 feet in diameter and 7 feet 6 inches long. The intermediate buoys are 8 feet in diameter and 25 feet long. All rigging, except the riser pendants, is submerged at least 100 feet. The anchorage is designed to hold ships of cruiser size on one heading and in position within a 50-foot radius. Each leg can withstand 60,000 pounds' horizontal pull.

The placement procedure for TOTO II is given in Appendix F. Cathodic protection (discussed in part 5) was incorporated in the installation to increase its life to an anticipated 10 years.

A pioneer multileg system restraining a large submerged structure is represented by the SQUAW anchorage. A submerged dummy submarine (the SQUAW) was anchored in 6,000 feet of water off Point Loma, California, in November 1959. The anchorage failed in October 1964 after almost 5 years in place. The experience with this anchorage indicates the nature of future requirements for large submerged structures and the capabilities necessary for achieving them.

The anchorage configuration, as shown in Figure 4-12, consisted of the buoyant SQUAW hull held level at a depth of 200 feet by four lines to the bottom. Two of these lines consisted of catenary legs, attached to the bow and stern, to provide the primary restraint of the hull. The remaining two lines, which provided accurate depth positioning and trim, were of precise length and rose vertically from massive weights resting on the bottom to attachment points fore and aft on the hull. This configuration was chosen because the bottom was essentially level, and currents in the area are of low magnitude. The configuration does not, of course, provide equal holding power in all directions.

The major components of the two catenary legs included a 3,000-pound LWT anchor, three shots of 1-1/4-inch chain, and a 4,100-pound concrete sinker (Figure 4-12). The remainder of each catenary leg was 1-inch-diameter wire rope having a scope of 9,430 feet. This length was based on a horizontal tension of 8,000 pounds, which held the chain-rope juncture 25 feet off the bottom. The two vertical legs each were comprised of two shots of 1-1/4-inch chain at the bottom, a half shot at the upper end, and about 5,700 feet of 1-inch wire rope. The two concrete clumps at the bottom of the vertical legs each weighed about 25,000 pounds.

The hull of the SQUAW was positioned level so that its deck was 200 feet below the surface. The net buoyancy was 77,000 pounds. Of this force 15,700 pounds was balanced by the downward force exerted at the hull of each of the catenary legs, and 22,800 pounds was balanced by the force exerted on the hull by each of the supplementary vertical legs. Since the weight of each vertical leg in water was about 10,300 pounds, a net tension of 12,500 pounds resulted at each clump.

The design of the SQUAW anchorage included consideration of the effect of installation procedures. For example, the design value of the horizontal tension in the catenary legs, as initially conceived, was to be 10,000 pounds. This value would have resulted in a tension of 17,000 pounds during that phase of the installation when it was necessary for the hull to be surfaced. Errors in depth measurements also could have resulted in additional tension increments. Therefore, in order to provide a reasonable factor of safety, the design value of the horizontal tension was reduced to 8,000 pounds.

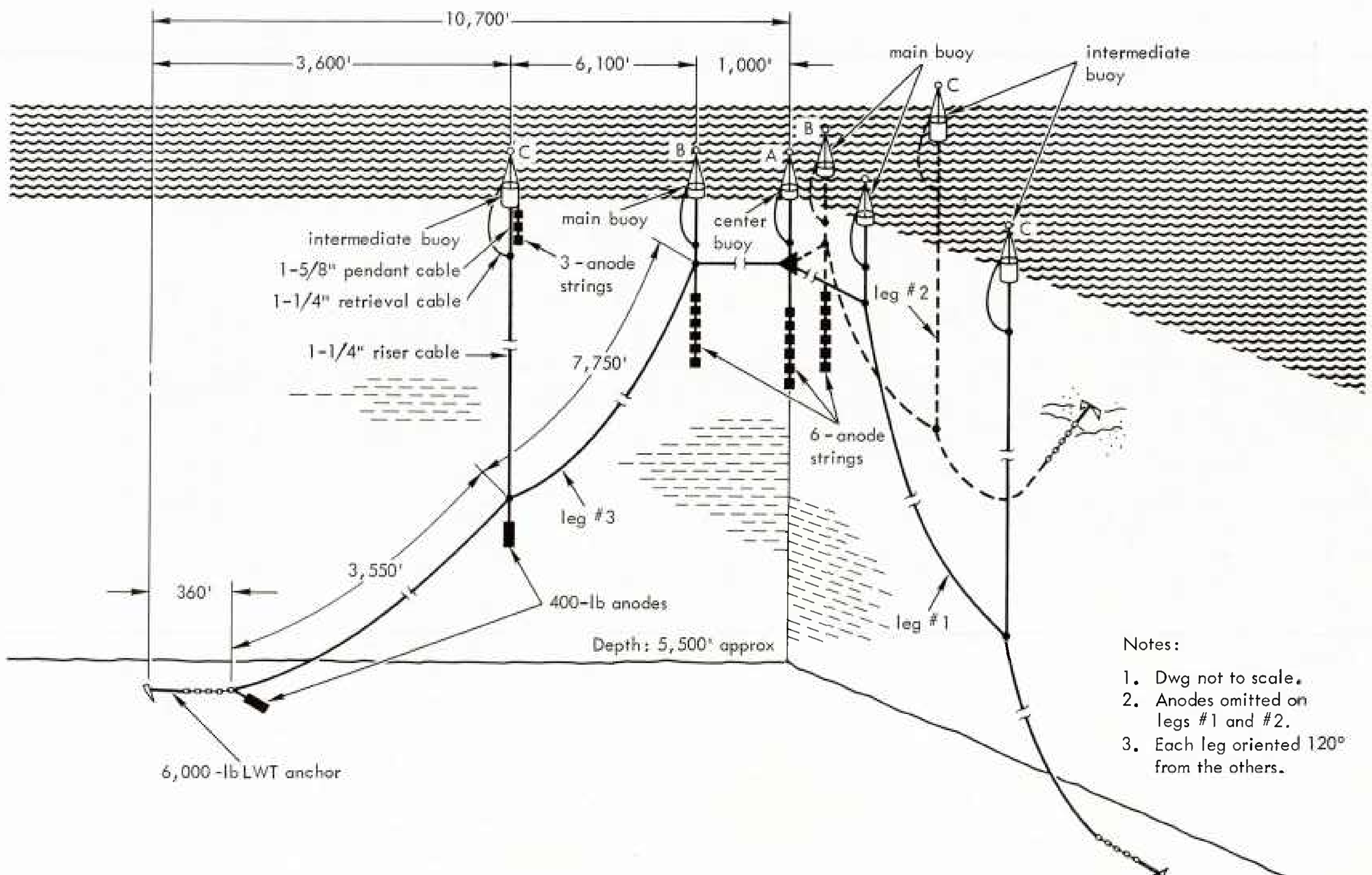


Figure 4-10. TOTO II anchorage system.

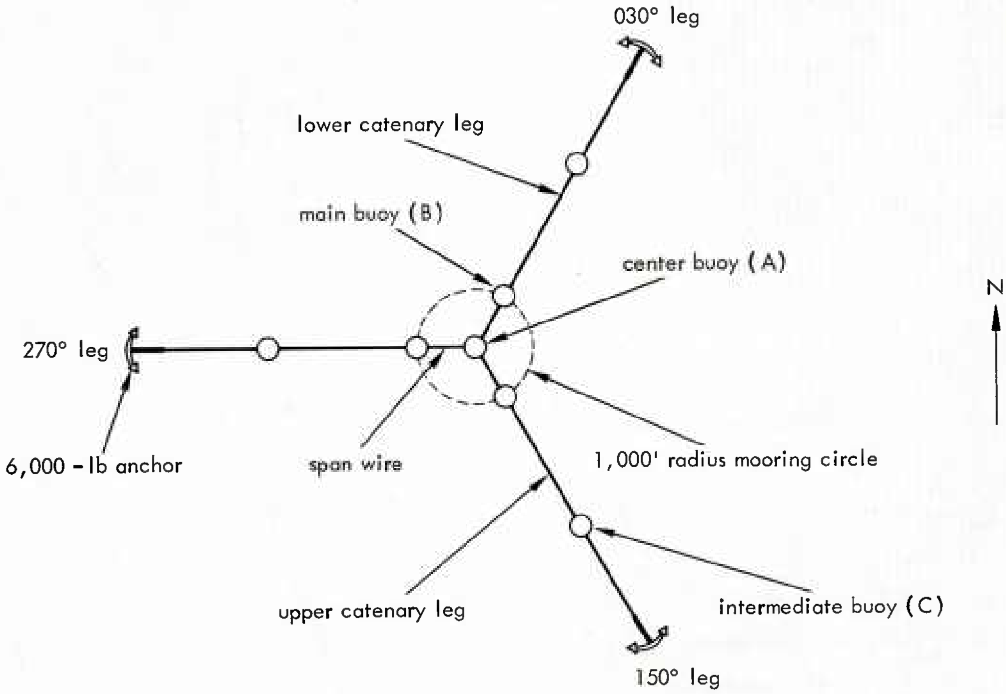


Figure 4-11. Plan layout of TOTO II moor.

Specific cause of failure of the SQUAW anchorage was traced to a chain link which was damaged or overstressed during installation of the system. The overall experience gained revealed certain limitations of the system and established valuable guidelines for future planning.

The detailed installation procedure for the SQUAW anchorage is given in Appendix G.

4-12. Bottom-Rest Systems. Bottom-rest systems are those underlying negatively buoyant structures that bear on the ocean bottom and depend on it for support in the form of footings or foundations. Anchorages as defined in this chapter include the means by which such bottom-rest structures, which may either be wholly submerged or extend above the water surface, are supported or restrained. Currently, few if any major structures of this type have been installed in deep water. However, offshore oil drilling rigs have been placed on the bottom in depths greater than 200 feet and farther offshore than 50 miles.

Three steel islands were erected in depths up to 200 feet at heights of approximately 90 feet above the surface between 50 and 200 miles off the New England Coast, and ARGUS ISLAND, a research station, was constructed by the U. S. Navy in 1960 in a depth of 200 feet on the Plantagenet Bank, 30 miles off Bermuda. In the ARGUS ISLAND, space is provided for housing electronic equipment, a general shop, maintenance facilities, storage, living accommodations for a 16-man crew, and even a helicopter landing area. The platform is supported by a truss-type structure consisting of four legs spaced in a 103-foot square at the bottom, tapering up to a 60-foot square at the top. The footings for this structure had to be firm and were basically piles cemented into the ocean floor. The top is 89 feet 6-1/2 inches above mean low water. The overall tower height is 290 feet 6-1/2 inches.

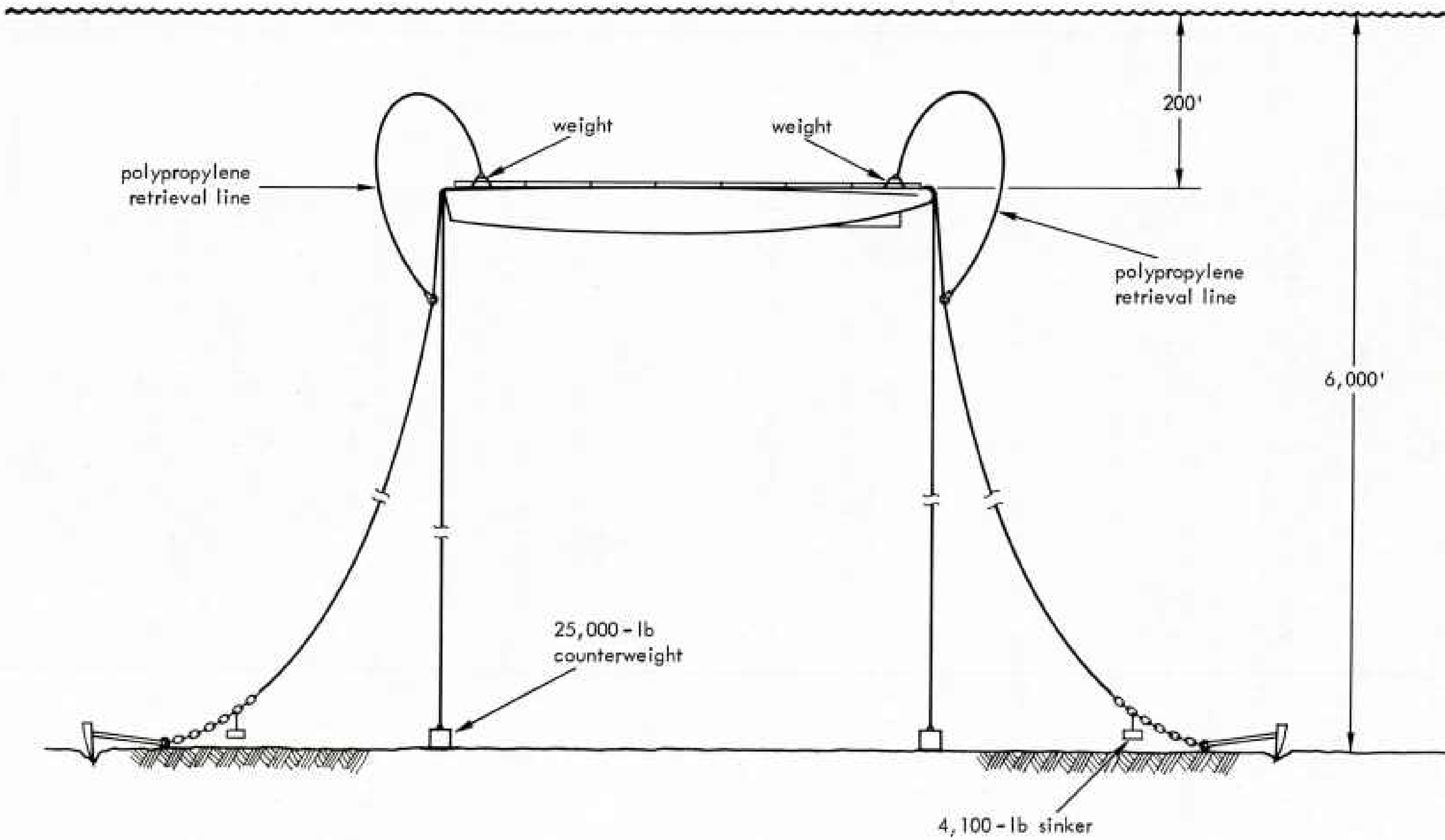


Figure 4-12. SQUAW anchorage system.

The ARGUS ISLAND construction is considered representative of current bottom-rest structure capability. It was built as a platform for research studies by Columbia University's Hudson Laboratories under contract to the U.S. Navy (McDermott, 1960). For its installation a "template" or jacket was constructed which served two purposes: as part of the structure rising from the ocean floor and extending above the surface on which the platform and building rested, and as a template through the four hollow legs of which the necessary holes in the coral bottom were drilled and through which the pile foundations were placed. The jacket is important here because it was the primary means by which the anchorage was achieved.

Description of the placement of the ARGUS ISLAND, as obtained from McDermott (1960), is as follows. The jacket was transported on its side, supported on specially constructed timber launching ways built on the deck of a cargo barge. The construction sequence is shown in Figure 4-13. On location, the jacket was launched into the ocean, rotated to a vertical position, and sunk into its final position on the ocean floor. After the jacket was set and leveled, sockets were drilled in the coral bottom to which 30-inch OD by 5/8-inch wall piles were grouted. Drilling of the sockets was accomplished by setting a small drilling rig on an auxiliary platform over one of the jacket legs. Using conventional oil-field rotary drilling tools, the hole was drilled through the 32-inch ID leg and underreamed to 36-inch diameter, to a depth of 50 feet into the coral.

After all four sockets were drilled and underreamed, the 30-inch OD piles were stabbed through the legs and seated on the socket bottoms. The piles were grouted to the coral foundation as well as to the jacket legs, i.e., the annular space between the pile and coral and between the pile and jacket legs were completely filled with grout. Standard oil-well-drilling equipment and techniques were used. After grouting, the tops of the piles were cut off to grade elevation, 2 feet above the top of the jacket.

A prefabricated deck section was mounted next and then a prefabricated two-story house was placed in two sections on the platform.

4-13. Dynamic Anchoring.

Dynamic anchoring (or dynamic positioning) is a method of maintaining a floating structure on station and oriented in one direction by means of power units that provide propulsive forces that counteract wind, wave, and other influences. All the following information on dynamic anchoring has been extracted from a report by Global Marine Engineering (1964).

A dynamic anchoring system comprises three basic features: (1) power units to provide the necessary propulsive forces, (2) a sensing device to determine the position of the surface structure relative to a fixed motionless datum point, and (3) controls capable of interpreting information received from the sending device and activating the amount and direction of power to the power units.

Power units may be integral parts of the structure or positioned away from the main structure on individual flotation units, but attached to the main structure by positive means such as cables or lines. The integral-part approach is preferable. In ships, it is desirable to use the same propulsion plant that normally moves the vessel as a part of the positioning power system. Unfortunately, the power units most convenient for dynamic positioning are not very efficient or reliable for continuous use as a ship's propulsion plant. Five types of power systems can or have been utilized in dynamic anchoring operations: (1) conventional ships' propellers, (2) horizontal-rotating controllable-pitch propellers (Voith Schneider); (3) outboard types, fully rotating around a vertical shaft; (4) thruster types, commonly called "bow thrusters," and "active rudders"; and (5) hydraulic jet types.

Horsepower requirements for dynamic anchoring must be a compromise between economics and desired degrees of fixity in various sea states. Winds and current forces are the most serious factors to overcome. Wave action is also serious, but is not usually a determining factor, because it is cyclic in nature and structures reacting to wave action alone would move in a circular motion in one general location. Consequently, it is not practical to try to counter this motion entirely, if at all.

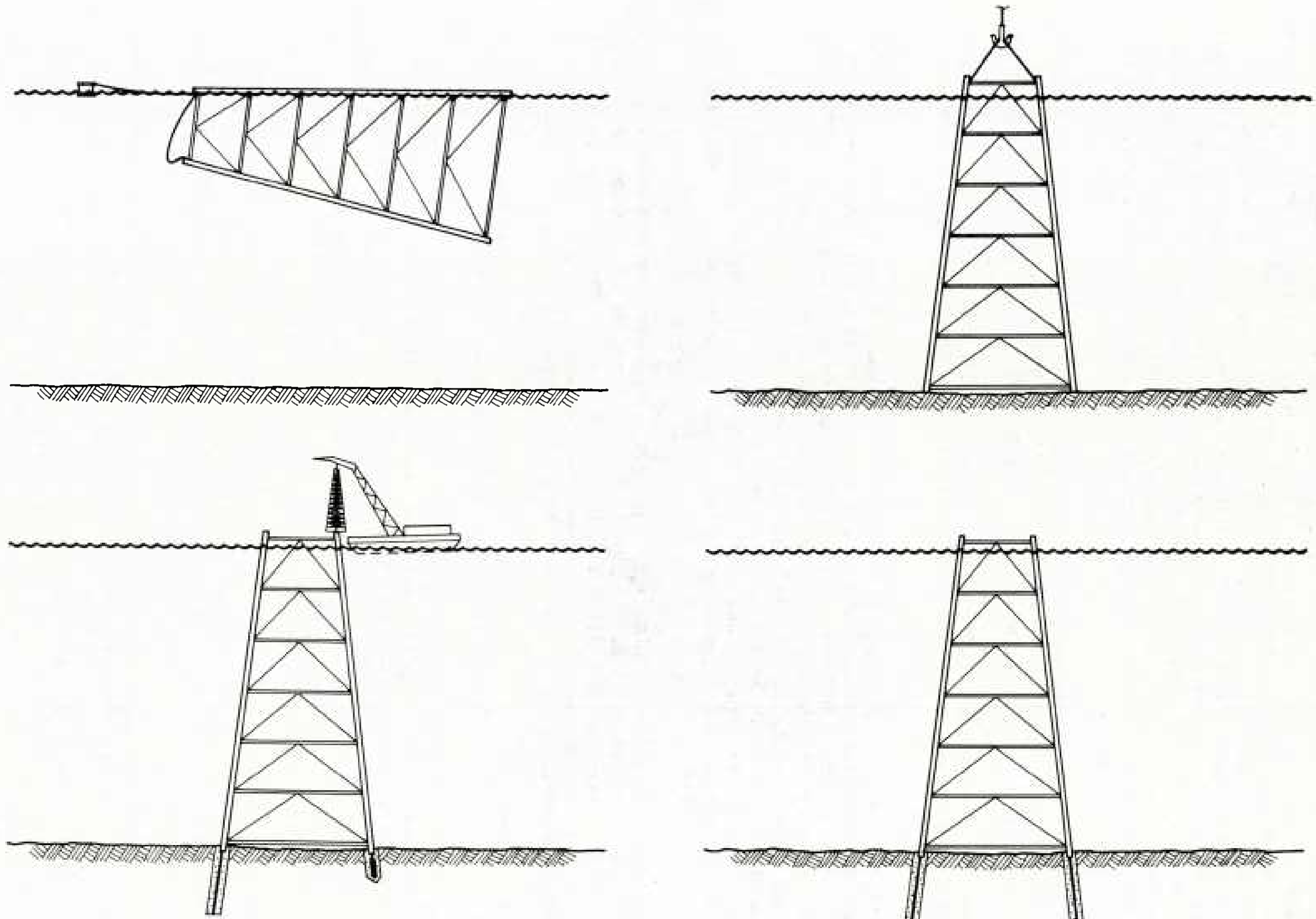


Figure 4-13. Construction sequence of ARGUS ISLAND anchorage system.

For ship-type surface structures, an approximate method of determining required horsepower is to establish maximum water conditions anticipated and the direction of prevailing winds and currents. Wind forces are then estimated using the formula $F = 0.004\ AV^2$, where A is silhouette area in square feet and V is wind velocity in knots. The current-drag forces are estimated from the formula $F = CAV^2$ where C is a coefficient that varies from 1.6 on a bow current to 3.0 on a beam current, A is the underwater silhouette area in square feet, and V is the current velocity in feet per second. Horsepower in propeller-positioning devices should be estimated at about 25 pounds of thrust per horsepower. Experience to date and preliminary design work seem to indicate that dynamic anchoring horsepower is between 0.25 and 0.5 times the displacement tonnage.

Three types of sensing devices have been used to relate to the fixed datum point: (1) sonar beams reflecting from underwater transponders prelocated in a known pattern around the location, correlated by triangulation through a computer which transmits power and directional signals to the power plant; (2) radar similar to (1), except that radar reflections are used to land targets or to surface buoys; (3) taut-wire line anchored to the ocean bottom with accurate detection of wire line angularity through tiltmeters, transmitting power impulses through a computer as in (1) and (2).

Currently, the taut-wire line method is the most practical, easiest, and quickest to use. One limitation of this system is the slowness and/or lack of response of wire line in deep water. In shallow water depths, 2,000 feet or less, the wire line seems to function and gives reasonably quick response to surface motion. Another handicap is that the taut-wire line system induces the complication of correction due to the rotation of the vessel in azimuth. This would be no problem if the taut-wire line could be run direct through the center of rotation of the surface vessel, but this is not usually the case. Usually the most desirable location for the taut line may be as far as 100 feet or more from the axis about which the vessel rotates in azimuth.

Radar systems seem to have an advantage, at present, over sonar. Present sonar does not permit very accurate returns due to the quite wide resolution of the sonar beams. In using sonar in water deeper than 500 to 1,000 feet, it is advantageous to mount the transponders on submerged buoys to reduce travel distance and allow horizontal signal paths. Horizontal paths reduce errors caused by differences in density with depth. It is apparent, then, that in most ocean locations submerged buoys are required for sonar. Also, out of sight of land, the radar system requires buoys at strategic positions. The setting of buoys in deep water is difficult and expensive and frequently the buoys are lost in storm action.

Whatever the sensing device used, controls can be manually activated by the operator through a "joystick" arrangement. With adequate power provided, a fixed position can be held through common navigation devices such as radar, pelorus sight, sonar and depth sounders. The controls also may be automatic. The automatic controls are most sensitive and provide quicker response and therefore retain more accurate position than does manual control. Since equipment failure in marine environments is commonplace, automatic systems should be installed with dual standby overriding manual control equipment.

Except in cases of malfunction of equipment, a fixed position can be held very closely to the available datum point, even with manual, round-the-clock control. This was done on the Phase I, Project MOHOLE, wherein a surface movement of 100 yards was considered an extreme movement.

Reports from ships carrying dynamic-positioning equipment indicate that no problems should be experienced in keeping position to within 5 percent of the water depth. An example of a ship with such equipment is the SS EUREKA, offshore drilling vessel operated by the Shell Oil Company. This ship is outfitted with bow and stern propulsion units, extending below the keel and capable of operating in a full 360-degree circle horizontally (Figure 4-14). The units can be controlled manually or automatically from information relayed electrically from a tiltmeter. The tiltmeter is a device secured to a light (1/8-inch) line leading from a boom over the side to a clump anchor on the bottom (Figure 4-15). It registers deviations between the line and the ship, relaying this information to the instruments which can translate it into corrective action through proper controlling of the bow and stern propulsion units. The line remains taut through the efforts of a deck-mounted, compressed-air-operated winch. The two propulsion units can be operated individually or together.

This ship has used the system described in 3,500-foot depths with conditions of 40 mph winds and 20-foot waves, and maintained continuous drilling operations. In one test, the automatic control system held the vessel within a 60-foot-diameter circle at 1,000-foot depth for 27 hours (Shatto, 1962).

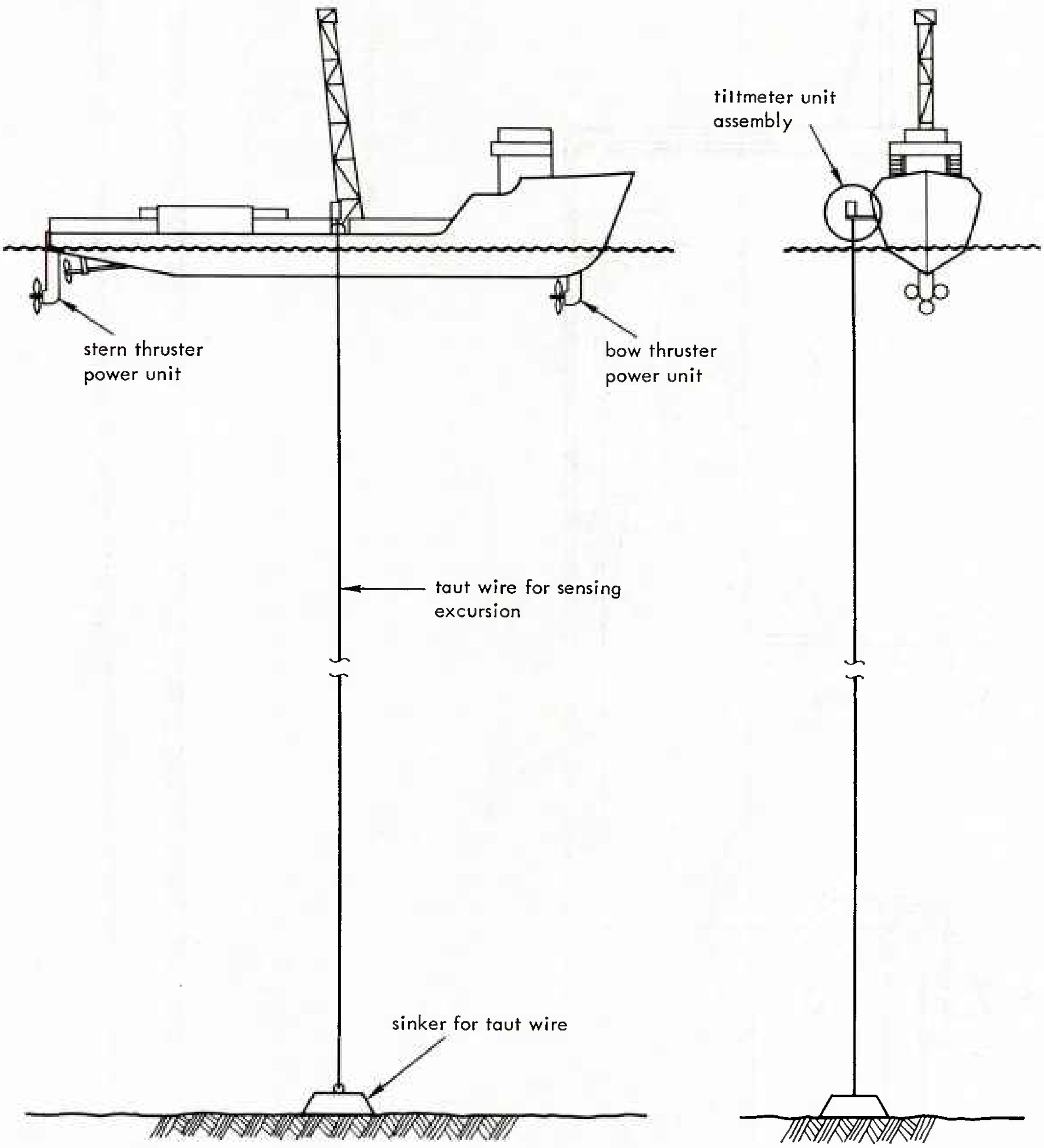


Figure 4-14. Dynamic-positioning vessel SS EUREKA.

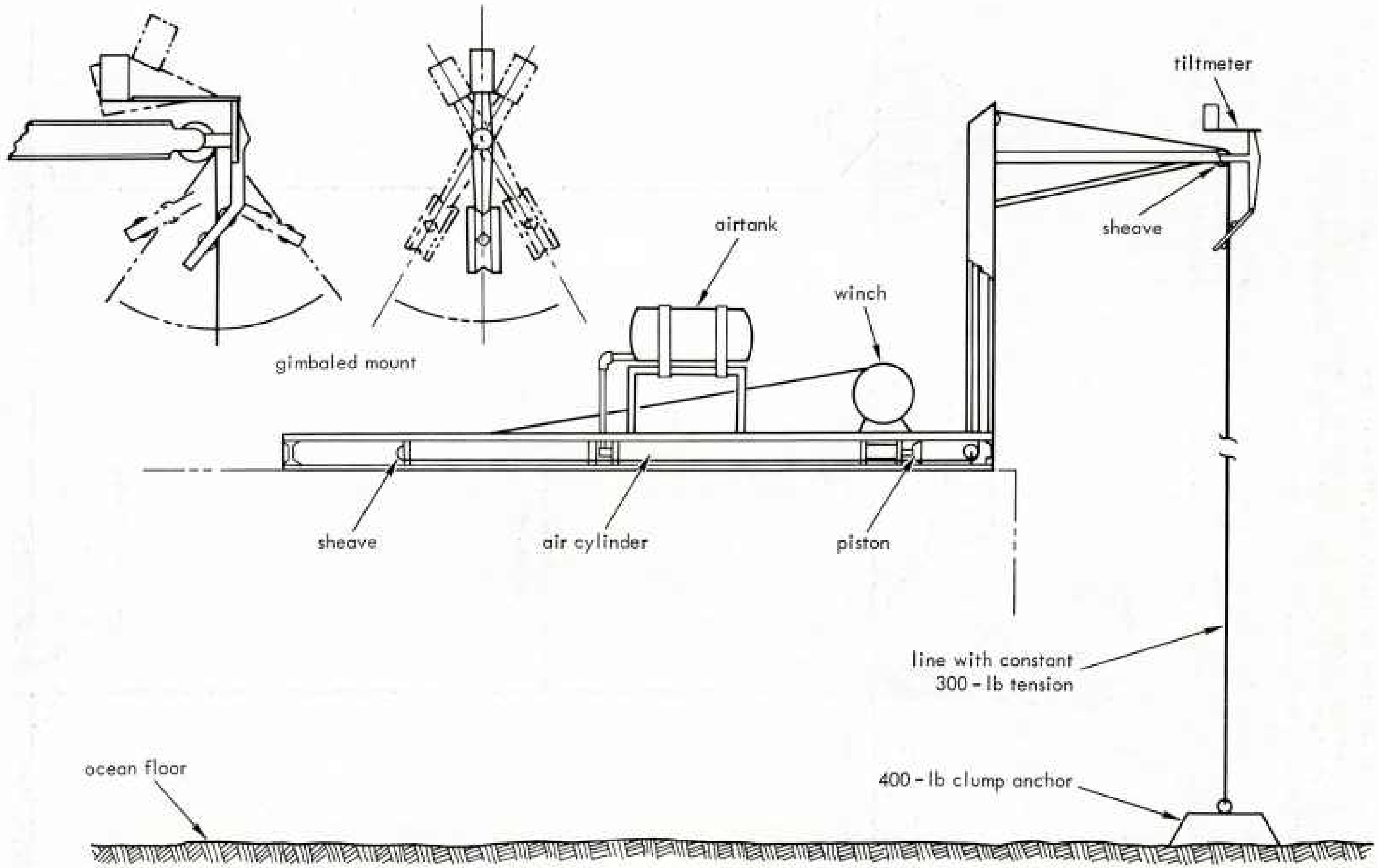


Figure 4-15. Tiltmeter for SS EUREKA.

PART 5
PROTECTION AND MAINTENANCE

5-1. GENERAL.

Protection and maintenance of buoys, anchorage systems, and their appurtenances against ordinary wear and deterioration and against damage from collision, vandalism, corrosion, and fouling are a major problem in shallow water. In deep ocean areas the problem is intensified with depth, distance from shore, and the difficulty or impracticability of surveillance, repair, and replacement. Until submersibles become serviceable at great depths and useful diving work can be performed below present levels, protection and maintenance must be largely preventive.

Protection at all levels can be accomplished partly through the use of coatings, partly through cathodic means, and partly through design precautions such as the incorporation of signals into anchorage systems.

5-2. METHODS.

5-3. Coatings.*

A protective coating should have the following properties: (1) optimum adhesion and capability of forming a hard film to resist abrasion, (2) ease of application by unskilled workers, (3) quick-drying capacity; (4) resistance to sea water, (5) antifouling characteristics, and (6) color-fast nature.

An investigation by the U.S. Coast Guard indicates that vinyl paints are the most effective protective coatings for buoys. According to a Coast Guard Civil Engineering Report (1957), vinyl paints have outstanding adhesion characteristics, durability, and gloss retention. They are fast drying, reduce marine growth more than other paints, and are highly impermeable if proper thickness is applied. A minimum thickness of 6.0 mils is recommended. Another advantage for vinyl paints is that at vapor concentrations well below the explosive limit, and below toxic concentrations that will produce ill effects on human beings, the solvents in vinyls give a positive odor warning. The Coast Guard converted to the vinyl system in 1951. Greater success than anticipated was attained.

In a more recent study conducted in Germany (Bohnsack, 1960) a zinc-dust paint was judged to be the most effective and economical protective coating system. The following minimum film thicknesses of zinc-dust paints are recommended as a result of the German tests: underwater, 200 microns; topside, 140 microns; and boot-topping (splash) zone (exposed to abrasive-action of ice), 250 microns. Inadequate thickness rapidly lessens corrosion resistance and anti-fouling properties.

Another type of coating that shows promise for application to marine structures is epoxy resin. The first domestic patent on an epoxy resin was granted in 1943. However, it was not until the 1950's that marine application was exploited. According to a symposium report by the Shell Oil Company (Shell Oil, 1963), properly cured epoxy resins are characterized by the following properties: (1) excellent chemical resistance, including concentrated acids and bases, (2) excellent adhesion to almost all surfaces, (3) good water resistance, (4) good electrical insulation properties, (5) extreme hardness, (6) good abrasion resistance, (7) good solvent resistance, and (8) good resistance to heat and cold.

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* Information on coatings as presented here applies chiefly to buoys, but is also applicable to other anchorage gear near the surface.

In a variation of the use of epoxy resin as a protective coating for marine application, a new coating system has been developed which is comprised basically of two components, an epoxy resin and a polyamide resin (Shell Oil, 1963). Individually, each component is stable for an indefinite period. Once thoroughly mixed in the prescribed ratio, however, components are converted by chemical reaction into tough, resistant, adhesive polymers that will not melt, flush, or flow even under heat or pressure. This mixture of resins was applied to cleaned and uncleaned surfaces in the splash zone on offshore oil-drilling rigs. Results were good. The clean surface was still intact and practically free from corrosion after 18 months' service. Where the surface had not been cleaned, the coating was easily removed after 8 months' service, taking with it the scale, rust, and barnacles that originally were present on the surface of the metal.

Epoxy-resin coatings and their variations can be applied underwater at reasonably cold temperatures. One such application was made at Norfolk Naval Shipyard when a damaged ship hull was sand-blasted and manually patched while floating in 40°F water. The coating required 3 days to harden. Inspection a few weeks later indicated satisfactory performance with no observable corrosion.

A long-range investigation of the effectiveness of coatings and cathodic systems for buoys is underway at the Naval Civil Engineering Laboratory (Drisko, 1963-1964). A wide variety of coating and primer combinations (Table 5-1) is being tested. Final results and conclusions are not yet available, but preliminary evaluations are listed in Table 5-2. (See also Figures 5-1 and 5-2.) A more detailed analysis of the coatings is presented by Drisko. Some initial recommendations resulting from this NCEL investigation include: (1) removal of side-hanging chains and other nonfunctional appendages from buoys, (2) use of pads to protect the coated surfaces of buoys against abrasion during handling, (3) use of coated bolts for securing wooden fenders to buoys, (4) adherence to sandblasting and coating-application procedures recommended in specifications of suppliers, (5) coating of buoys as soon as possible on the same day after sandblasting, and (6) abstinence from application of coating when the humidity is greater than 85 percent or when the temperature is below the minimum set for the particular coating.

5-4. Cathodic Systems.

Corrosion of metallic surfaces exposed to sea water results from the migration of electrons from exposed areas. When this happens, ions in the ambient sea seek to combine with the metal ions left by the departing electrons. This causes the formation (corrosion) of metal compounds such as oxides, hydroxides, and chlorides. Cathodic protection as applicable to deep ocean constructions is the control of electrolytic action of an underwater structure by use of an electric current in such a way that the structure is made to act as the cathode instead of the anode of an electric cell. This induces the metal electrons to migrate toward, instead of away from, the metal surface, and theoretically prevents or retards corrosion.

The two most generally accepted cathodic methods of retarding corrosion are: (1) use of sacrificial anodes, made of magnesium, zinc or a combination of these, which are gradually consumed and provide a correct flow of electrons that neutralizes potential differences on the protected surfaces, and (2) use of insulated, permanent anodes and electrically impressed current. The first type of anode has the disadvantage of limited life; the latter type requires greater care in positioning in relation to parts to be protected than the other, and is more expensive.

Studies conducted at the U.S. Naval Civil Engineering Laboratory (Hanna, 1961) determined that steel hulls could be protected against corrosion in ocean water over long periods by use of galvanic zinc and magnesium anodes. The most successful anode protection of offshore buoys has been attained through use of closely mounted anodes, whether sacrificial or permanent. Buoys designed with consideration for cathodic protection are constructed with sea chests to accommodate the protective system.

Table 5-1. Coating and Primer Combination Tests

Coating System		Primer			Additional Coats			Total Thickness (mils)
Number	Description	Type	Coats (No.)	Thickness (mils)	Type	Coats (No.)	Thickness (mils)	
1	Urethane	Urethane	1	2	Urethane	3	8	10
2	Epoxy	Epoxy	1	4-5	Epoxy Epoxy Antifouling	1 1 1	4 3 4	8-9 11-12 15-16
3	Epoxy Polyester	Epoxy	1	4-5	Polyester Antifouling	2 1	5-6 4	9-11 13-15
4	Epoxy-Coal Tar Epoxy	Epoxy	1	4	Coal Tar Epoxy Epoxy Epoxy	1 1 1	4-5 4 4	8-9 12-13 16-17
5	Coal Tar Epoxy-Phenolic	Coal Tar Epoxy	1	5	Phenolic Phenolic	1 1	4-6 6-7	9-11 15-18
6 & 6C	Phenolic Mastic	Mica-filled Phenolic	1	10-11	Phenolic Mastic	1	8-9	18-20
7C	Phenolic	Wash Primer Phenolic	1 2	1/2 4-1/2	Phenolic Antifouling	1 1	2-3 3	7-8 8
8	Phenolic Alkyd	Wash Primer Phenolic	1 2	1/2 4-1/2	Alkyd Antifouling	1 1	2-3 3	7-8 8
9	Vinyl	Wash Primer Vinyl	1 4	1/2 6-1/2 - 7-1/2	Vinyl-alkyd Antifouling	3 2	4 4	11-12 11-12
10	High-Body Vinyl	Vinyl	1	2	Vinyl Vinyl	2 1	5-6 2	7-8 9-10
11	Vinyl Mastic	Vinyl Phenolic	1	1-2	Vinyl Mastic	2	12-13	13-15
12	Inorganic Zinc Silicate Vinyl Mastic	Inorganic Zinc Silicate Vinyl Phenolic	1 1	4 1-2	Vinyl Mastic	1	5	10-12
13 & 13C	Saran (Formula 113/54)	–	–	–	Saran	8	8	8

Table 5-2. Overall Rating and Length of Service for Buoy Coatings

Coating System		Length of Service (days)	Overall Rating
Number*	Description		
1	Urethane	417	good
2	Epoxy	374	good
3	Epoxy-Polyester	374	fair
4	Epoxy-Coal Tar Epoxy	417	good-fair
5	Coal Tar Epoxy-Phenolic	376	good-fair
6C	Phenolic Mastic	376	good
7C	Phenolic	228	good
8	Phenolic-Alkyd	227	good
9	Vinyl	250	excellent
10	High-Body Vinyl	341	fair
11	Vinyl Mastic	418	poor
12	Inorganic Zinc Silicate-Vinyl Mastic	418	fair
13	Saran	376	good-fair
13C	Saran	382	good

*Numbers refer to Table 5-1 coating systems.

Figure 5-1. Improperly applied vinyl coating being stripped from buoy.

Figure 5-2. Medium amount of fouling on buoy coated with System 6C, Table 5-1.

More recent tests, as reported by Drisko (1963-1964), have shown that 10-foot-diameter painted mooring buoys may be protected over their entire underwater surface with a single 70-pound controlled magnesium anode with a consumption rate of 6 to 10 percent per annum, corresponding to a cost of about 3 cents per square foot area per year (Littauer, 1964). (See also Figures 5-3 and 5-4.) Protection of offshore mooring buoys is a paramount problem today. Buoys should be designed to accommodate protection devices, with limitations of the various systems now in use being considered.

Cathodic protection systems were designed and assembled for the TOTO II moor. Since the location of TOTO II precluded bringing power from shore and power requirements precluded use of batteries located in buoys, and since internal combustion engines were noisy and unreliable, only a galvanic anode system was deemed acceptable in TOTO II cathodic protection (Waldron, 1962). Magnesium anodes of H-1 alloy composition (5 percent Al, 3 percent Zn) were used for each of the three legs and below the center buoy: (a) a single 10- by 10- by 60-inch anode, weighing 400 pounds, was used at the bottom anchor chain ring and at the ground ring under the intermediate buoy; (b) a string of six anodes, each 5 by 5 by 36 inches, weighing 60 pounds, was used below the ground ring under the main buoy and again below the flounder plate; and (c) a string of three of the 5- by 5- by 36-inch anodes was used under the intermediate buoy. Refer to Figure 4-10 of the preceding part for locations of cathodic protection on the moor.

Figure 5-3. Cathodic protection system installed with anode under protective steel bars.

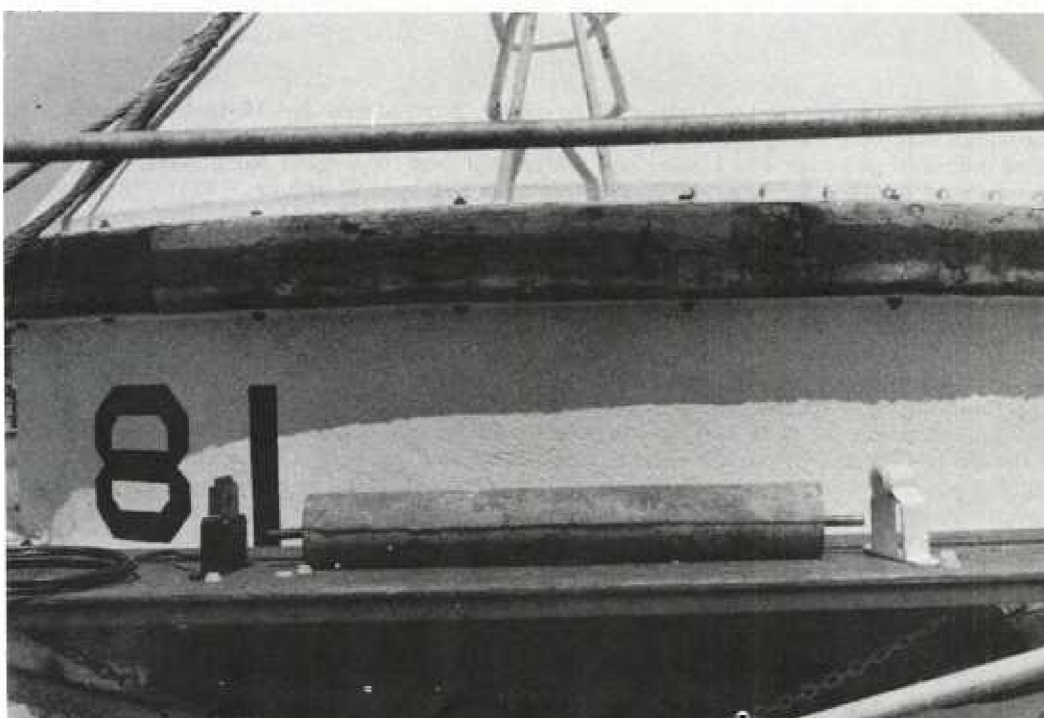

Figure 5-4. Cathodic protection system showing (from left to right) mounting bracket, sacrificial magnesium anode, and control head.

Figure 5-5 shows details of the 400-pound anode attached to the ground ring about 4,000 feet under the intermediate buoy in TOTO II. The 400-pound anode at the end of the 360-foot anchor chain was attached in a similar manner. Electrical leads of 3/0 flexible welding cable connected the anodes to the tensioned shackles. Chain under tension maintains low metallic resistance between links. For this reason, all anode leads were welded to tensioned members of the moor. Electrical leads were fitted at both ends with brazed steel straps that were welded to the tensioned connections.

Figure 5-6 shows details of the attachment of the six 60-pound anodes in a string at the ground ring under the main buoys. An identical anode string was attached under the center buoy with the exception that a galvanized flounder plate was used in place of a ground ring. The three-anode strings attached to the intermediate buoys were constructed similar to the six-anode strings with the exception that the number 3/0 flexible welding cable was only 50 feet long and extended 8 to 10 feet beyond the thimble and shackle attached to a pad eye on the underside of the buoy.

The TOTO II moor is believed to represent the most complex and extensive wire rope apparatus in which cathodic protection has yet been attempted. Waldron (1962) discusses this major application in greater detail.

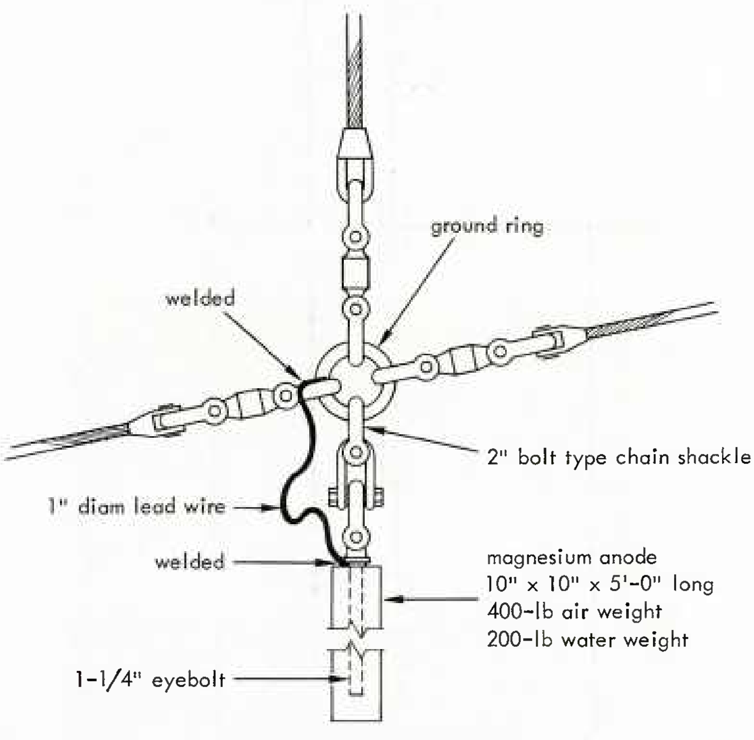

Figure 5-5. Details of 400-pound anode attached to ground ring under intermediate buoys of TOTO II anchorage system.

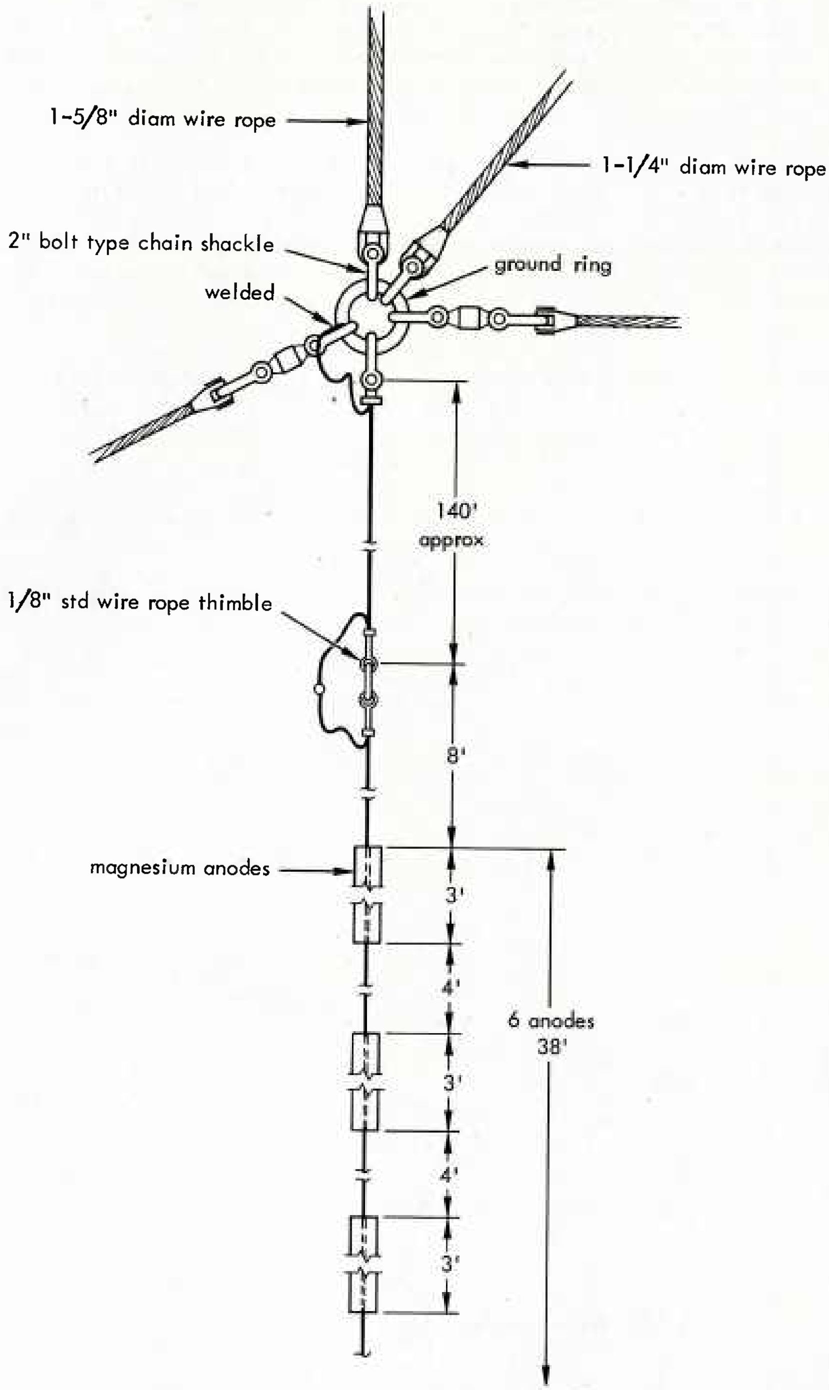

Figure 5-6. Details of six-anode string under main buoys of TOTO II anchorage system.

A cathodic protection system for an anchorage should have fittings compatible with the components of the anchorage and should be capable of installation during its assembly and placement. The positioning of the anodes and the sequence of installation must be planned so as not to complicate the already difficult task of placing the anchorage system. Some recommended areas for improving cathodic protection of future anchorages include: (1) development of means to examine periodically and replace anodes that become exhausted; (2) attachment of anodes at more frequent intervals (less than 1,000 feet); and (3) use of durable and protective wire rope coatings in conjunction with cathodic protection.

5-5. Other Methods.

Abrasion, stress fatigue, wear, bending, kinking, and similar problems common with conventional installations are in general greatly intensified in deep ocean installations. The portion of the connecting apparatus lying on the ocean bottom or likely to come into contact with the bottom as the moor moves under various load conditions is subject to high abrasion and wear. Near the surface, waves cause ceaseless motion, resulting in chafing, jerking, and fouling of slack lines. Consequently, particular attention should be directed to these sections of the anchorage system.

Near the bottom, consideration should be given to employing abrasion-resistant metal. Special steels and alloys may be justifiable in some instances to obtain higher strengths and to reduce danger of stress fatigue. Near the surface, some protection can be attained by including shock mitigators, swivels, and special connections to minimize friction and abrasion between system components.

The high conductivity of sea water makes essential the adequate separation of dissimilar metals. The potential difference between even hot-dipped and electrolytically galvanized parts can be sufficient to cause failure if they are submerged and in contact for several months. The oxygen concentration in some areas of the open ocean is as low as 0.15 ml/l at mid-depths. Many metals including stainless steels are inadequately protected at such low concentration.

A means of signaling attack on, damage to, or potential hazard to deep ocean anchorages, as well as signaling their failure or imminent failure, might be considered for incorporation into design. Pingers, transponders and similar devices might be used for this purpose. Such devices might also serve as traffic warnings to undersea and surface vessels. As inner space becomes more highly used and less unencumbered, traffic and obstruction problems are likely to develop.

PART 6
OPERATIONS AND SERVICE

6-1. GENERAL.

This part deals with equipment and procedures used in installing an anchorage in deep ocean areas. Equipment is considered according to inboard use and underwater surveillance. Procedures discussed include assembling anchorage components, lowering objects to the ocean bottom, and embedding anchors in the bottom.

To illustrate the complex procedure of installing a major anchorage, the placement of the TOTO II system will be considered. This operation combined the efforts of seven ships, two workboats, and the specially trained personnel of the Service Force, Atlantic Fleet. Operations on a comparable or even greater scale can be anticipated for other major deep ocean moors.

A recent report by Jones (1965) describes placement and retrieval operations which are pertinent to those discussed here.

6-2. EQUIPMENT.

6-3. Inboard Use.

6-4. Winches. Perhaps the single most important item of inboard equipment is the winch. Winch capabilities directly influence installation procedures, as well as design. For example, the basic limitation in regard to the TOTO II moor was winch capacity (Hydrospace, 1964). Ideally, winches should have high speed, high capacity, and accurate sensitive controls that provide for widely variable speed and automatic tension. Such controls are available and permit the machinery to "tend" the cable without the need for an operator (McClinton, 1961). If loads exceed a preset value, the winch pays out cable; if less than the preset value, it hauls in cable. It is insensitive to small tension changes. A winch of approximately 400-feet-per-minute, 90,000-pound capacity would appear to be desirable for major contemplated installations. Winches should have a large storage capacity to handle the great quantities of rope involved in deep anchorage. To prevent damage to ropes they should be capable of an assured level wind on the drum at all speeds. Another highly desirable characteristic is a driving system independent of the drum, because in handling great lengths of rope it is necessary to remove most of the tension before reeling the rope onto the drum. If this is not done by means of an independent driving system, the wire rope may "knife" down through lower layers, causing severe damage to itself and to the drum. This situation is even more critical in the case of an elastic nonmetallic rope. If such rope is wound onto the drum in a stretched, high-tension condition, it will eventually crush the strongest drum in addition to causing damage to lower strands of rope.

Winches should have footage indicators attached so that an accurate count of the footage of rope on or off the drums is always immediately available. Also, a tensiometer (discussed in part 7) should be used in conjunction with the winch so that the amount of tension in the line is always precisely known. Another characteristic invaluable in lowering components of great weight is that of constant tension. A satisfactory constant-tension winch incorporating the speed-and-capacity characteristics mentioned above is not known to be developed at this writing. (It should be noted that "constant tension" is not to be confused with "automatic tension," which is insensitive to small tension changes.)

The winch used in the anchoring of the USNS JOSIAH W. GIBBS in depths to 20,000 feet consisted of a dual-drum traction unit, a stowage unit having two cable drums with a level wind, and a power unit utilizing a 150-hp AC motor-driven hydraulic pump (Beck, 1962). Each of the power units was mounted on a separate bed plate with the power unit bed plate containing the hydraulic system oil pump as an integral part. The traction unit provided for hoisting and controlled paying out of the cable was mounted on the weather deck of the ship near the stern.

The winch was rated nominally as having 30,000 lb pull at 133 fpm and 8,800 lb pull at 460 fpm. The speed was continuously variable within these ranges. The stowage unit stored the cable retrieved by the traction unit, and tension was maintained between stowage drums and traction unit during retrieval or paying out of cable. The tension varied from 400 lb to 2,000 lb.

6-5. Tensiometers. A tensiometer is an instrument used to measure tension in an anchorage line. One such device was developed at David Taylor Model Basin for use in implanting the TOTO II anchorage (Figure 6-1). It not only records continuously the tension on the line as the line is being paid out, but also records the tension required in securing the span wires in the final phase of the operation. This instrument is a dynamometer type in which the line under tension passes over one wheel, under the recording pressure wheel, and over the final wheel to the rolling chock. The amount of displacement of the pressure wheel is calibrated to the tension in the line. In this manner, tension can be recorded at any and all times during implantation of the anchorage system.

6-6. Rolling Chocks. The rolling chock for deep ocean use is a special deviation from the standard rolling chock whose use is sometimes deemed necessary in anchoring with wire rope (Figure 6-2). A larger than ordinary drum-type horizontal roller is required to prevent strands from breaking from too sharp a bend. Besides the two vertical rollers found on the standard roller chock, a top guard spanning the vertical rollers is required. Danger to personnel and equipment can be lessened by thus keeping captive the line under tension.

6-7. Sheaves and Pulleys. Sheaves and pulleys of assorted types and sizes are necessary for the handling of many sizes and kinds of line. Charts are available showing acceptable sizes of sheaves for each size of wire used (U.S. Steel, 1963). Recommended sizes of sheaves should always be used, otherwise sharp bending from use of undersized sheaves and crushing of strands from oversized sheaves will cause damage and lead to premature failure in the line. Every precaution should be exercised to protect cables and lines because of high material costs and the difficulty or impossibility of repair or replacement of components.

6-8. "A" Frames. An "A" frame is usually located on the stern of a servicing ship. It provides a method of holding anchor line or chain suspended over the stern. In this position, instruments may be attached or detached and the line examined or serviced. The "A" frame is usually constructed so that it raises and lowers to different positions under mechanical, electrical or hydraulic control. Sometimes constructed in the form of a "U," the frames are composed of heavy structural steel capable of handling heavy tonnage loads (Beck, 1962).

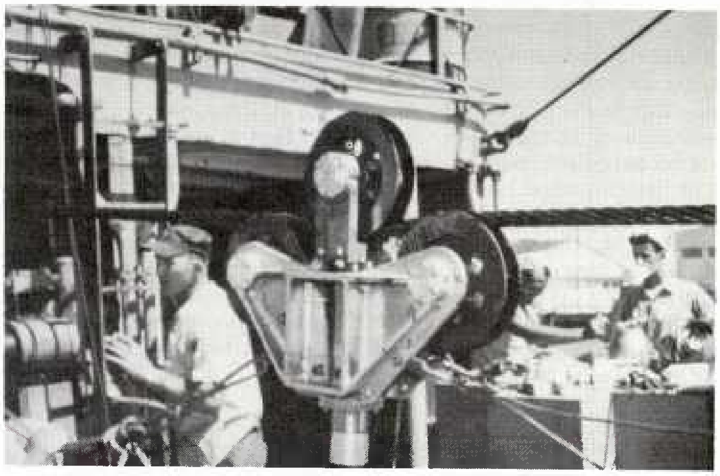

Figure 6-1. Running dynamometer.

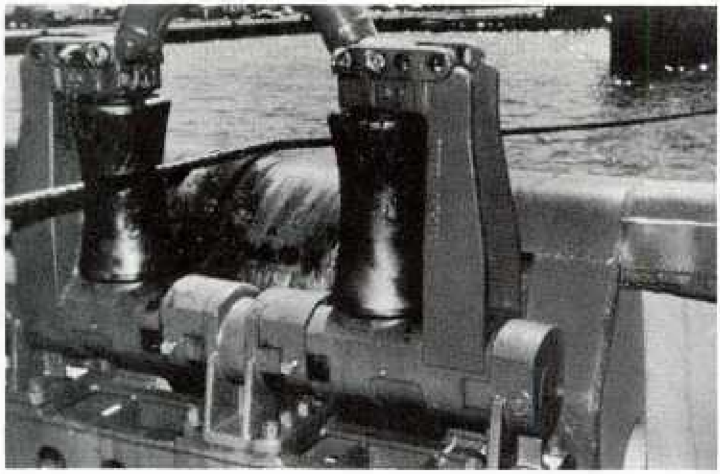

Figure 6-2. Rolling chock.

6-9. Other Equipment. Other inboard equipment items might well include a TV monitoring system, an azimuth indicator, a level indicator, a cross-level indicator, a windlass, and roller path guides.

6-10. Underwater Surveillance.

Equipment that can produce a picture of the sea bottom by reflected sound waves has recently been patented for the Navy (Compass Publications, 1964). Echoes can be reproduced on tape to serve as a strip map. A video image is produced that reportedly resembles what an observer would see if he were watching the ocean floor through a pipe. Cameras that can be lowered to practically any desired depth for scanning the bottom in oceanographic research have operated successfully, (Science, 1964). Figures 6-3 and 6-4 are examples of photographs that show details of the bottom.

Such equipment may well enhance bottom-survey methods used prior to installation of an anchorage. Although the camera-survey technique cannot be considered feasible to the degree desired for construction of anchorages, it does offer possibilities.

Deep-water-operating television techniques are being developed that may prove reliable for surveying and monitoring anchorage sites as well as anchorage components prior to, during, and after construction. Currently, however, severe limitations exist. According to Hitchcock (1964a), the range of an undersea visual detection system, i.e., the distance beyond which the target cannot be detected, is a widely variable quantity that depends upon such factors as positioning of illumination sources, sensitivity of the detector, amount of suspended matter in the water, and wave length of the illumination. It is estimated that at depths below the penetration of natural light, the detection range of an ideal target by illumination would be 300 feet. This ideal would seldom if ever be attained and the range would normally be considerably reduced, probably 30 to 50 feet. The limited vision range and the variability factors coupled with stringent criteria for transmitting television signals over long coaxial cables (1 to 7 miles) would appear to make difficult the practical application of TV for underwater viewing at the present time.

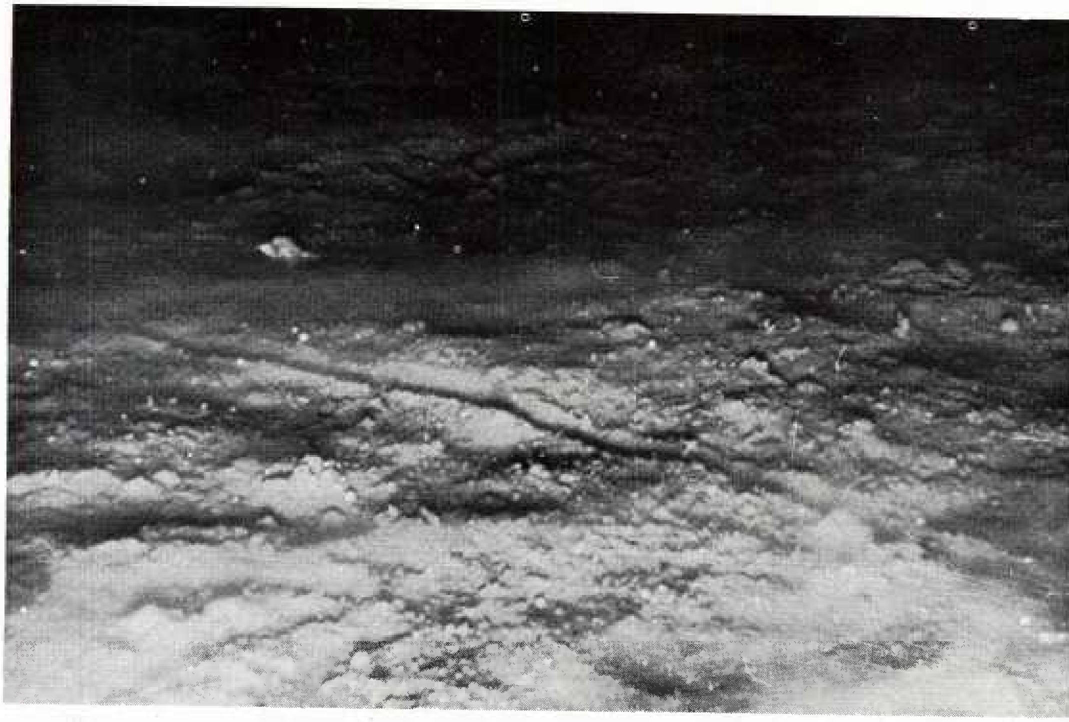

Figure 6-3. Photograph of ocean bottom at 6,000 feet at NCEL Ocean Test Site showing bottom disturbed by soil sampler.

Figure 6-4. Photograph of ocean bottom at 6,000 feet at NCEL Ocean Test Site after settlement of disturbance caused by soil sampler.

Piston-operating oceanographic coring tools have been used successfully to obtain soil samples in any desired water depth. The tools, lowered and raised on a rope or cable, have been specifically adapted to reduce disturbance during procurement of the sample and to securely retain it during retrieval. A photograph of one sampler user at NCEL and a soil sample obtained are shown in Figure 6-5. Depending on the softness of the bottom, samples to 100 feet in length can be procured.

A corer that requires no winch and no cable has recently been developed (Bowen, 1964-65). Essentially it is a gravity corer that free-falls with negative buoyancy. Upon contact with the bottom a triggering device releases two glass spheres which rise to the surface carrying a plastic sampling tube filled with the sediment sample.

6-11. PROCEDURES.

6-12. Assembly.

The term "assembly" is here used to refer to the gathering together of the components of an anchorage system prior to their incorporation into the system, and the incorporation of such units into a system. In general, the gathering together of the components should be done in such fashion that their incorporation into the system can follow a logical sequence. The incorporation of components may commence during the gathering process or at some stage in installation; this applies, for example, to certain subsurface buoys, floats, and buoyancy materials. It also applies to accessories such as cathodic protection devices and to connections and fittings. The best course is to establish, by careful planning, the least complicated assembly pattern compatible with desired objectives and available equipment. Such plans may well include consideration of: (1) surface stations of vessels involved; (2) methods and equipment for establishing and maintaining ships' positions relative to each other, to a central surface assembly point, and to a point or points on the ocean bottom; (3) surface and subsurface traffic lanes; (4) establishment of secondary assembly points (readiness points) where equipment and materials and personnel can be gathered in a state of readiness, to be brought to a central assembly and/or installation point as needed; (5) preparation of anchorage-system components for incorporation into a system in the natural order of such application, as exemplified in Table 6-1; and (6) careful inspection by qualified personnel of assembly-line components, procedures, and equipment before assembly begins; divers should, as far as possible, check assemblies at the installation to the limit of their diving depth.

Table 6-1. Components Utilized in each TOTO I Mooring Leg (Hydrospace, 1964)
(In approximate order of assembly)

3,000-lb LWT anchor
1-1/4" chain (one shot)
4,100-lb clump
1-1/4" chain (two shots)
1" wire rope (9,000 ft)
Buoy riser chain (100 ft)
Mooring buoy (12' diam. x 6')
1" wire rope (900 ft)

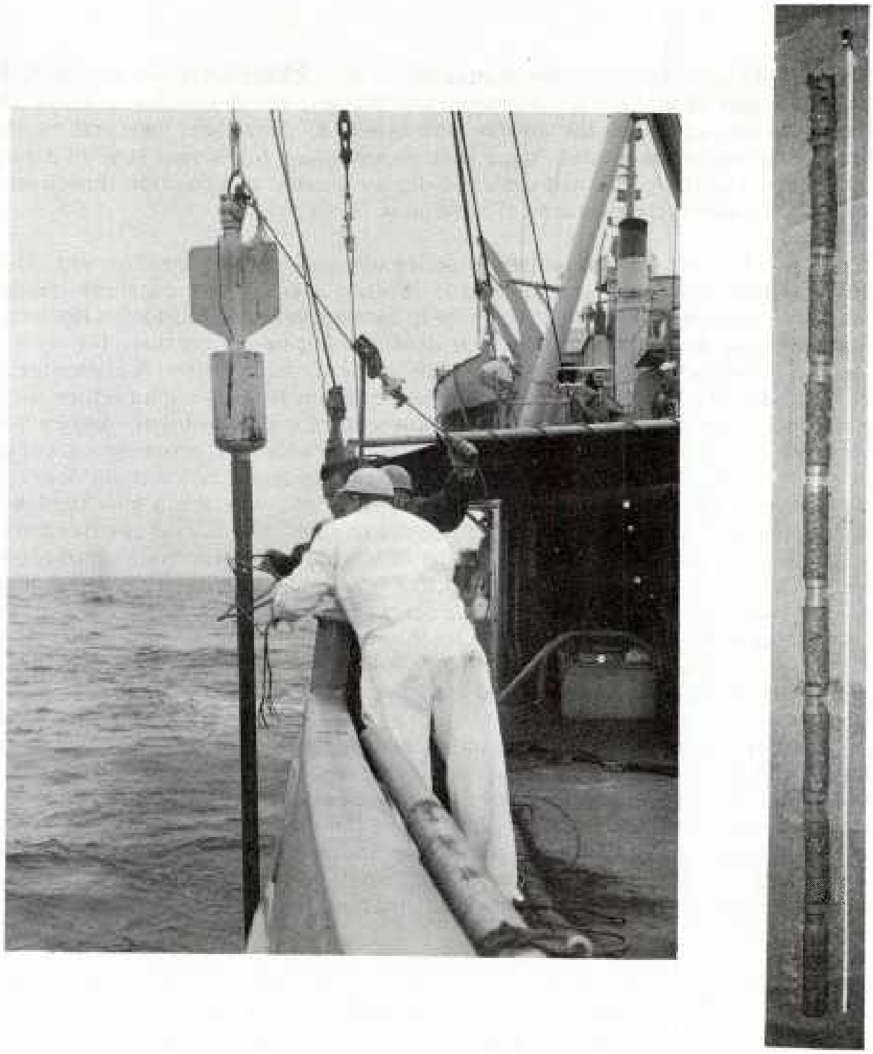

Figure 6-5. Bottom soil sampler used at NCEL and soil sample obtained from 6,000-foot depth at NCEL Ocean Test Site.

6-13. Lowering.

Methods of placing anchorage components on the ocean bottom range from free fall to carefully controlled lowering by winches and other machinery. The item to be lowered, its application, sturdiness, and requirement for precision placement are factors determining the procedure that is most practicable.

6-14. Controlled. For some installations, major components of anchorage systems must be lowered with care and precision to the bottom. Winches and other machinery not specifically designed for this operation must often be used. Excessive lengths and weights of lines, motions of ship or surface platform may cause vertical and rotational oscillations to develop and be amplified as a heavy object is lowered deep into the water. Also, the cable elongates under the tension of its own weight and that of the object it supports. If the tension is released too suddenly, the cable strands kink and seriously damage the cable. Experience in lowering a heavy instrument package 6,000 feet to the bottom of the Tongue of the Ocean off the Bahamas illustrates the difficulties that can be encountered. The package weighing 8 tons had to be set on the bottom in a gentle manner. As it neared the bottom, the descent was slowed to a rate that would not cause damage when the bottom was reached. However, vertical oscillation had become so great that the package struck the bottom with such force that severe damage resulted. Furthermore, the cable had unflexed due to tension and became irreparably kinked when the load was momentarily released (Prestipino, 1963).

Constant-tension and tension-compensating winches are undergoing development (McClinton, 1961). As yet they may not meet requirements. Until a satisfactory constant-tensioning mechanism is developed, a stable platform with minimum vertical motion is the best assurance of successfully lowering heavy objects to great depths. In this connection, the U. S. Naval Underwater Sound Laboratory at New London, Connecticut, has devised a computer program for lowering heavy objects in the deep ocean. The program relates such factors as cable elasticity and weight, speed of lowering, ship excursion, weight of object, and responsiveness of object, to movement in water (Whittaker, 1964). Even with this program, lowering operations require large ships in a calm sea. Precautions that can be taken in lowering operations include: (1) a wire-rope cable with a regular-lay type of construction, which has less tendency to untwist than other standard types of lay construction, should be used; (2) if load requirements permit the use of nonmetallic ropes, the latter should be of braided construction, stronger than the lay and not subject to kinking or twisting; (3) protective sheathing should be provided in sections of lines subject to abrasion or sharp edges. With reference to the latter, NCEL experienced a near-costly loss during the recovery of Submersible Test Unit No. 3. The STU had a sharp-edged specimen that bore against the polypropylene line during the 6,000-foot lift; by the time the STU broke the surface, the line had been cut and weakened.

Typical steps in lowering components of complex single-leg anchorages that incorporate submerged buoys and other features of multileg anchorages are shown in Figure 6-6. Here the buoy is lowered over the side and the anchor line streamed as the vessel moves to a position over the desired bottom location of the anchor. Then the anchor is carefully lowered to the bottom, care being taken not to damage instruments and connections as they are attached or pass through the ship line-handling equipment. To accomplish the lowering process as fast as possible, without permitting sudden relaxation of the line, it is desirable to attach a bottom-sensing device.

6-15. Free Fall. Free-fall procedures are the most rapid and are used in less complex buoy anchorage installations. Three basic free-fall methods are employed. In one the anchor is dropped and the attachment line allowed to pay out from shipboard as the anchor falls through the water. This method is practicable only for anchorage systems requiring small-diameter lines and/or buoyant lines. Its disadvantage is that the line trailing the free-fall object must move through the water at high velocity, causing payout difficulties at the surface and resulting in a large mass of material moving at relatively high velocity when the free-falling object strikes the bottom. This mass should be stopped by brakes at the surface, and a device is necessary to signal when to apply them. Even so, the line may become entangled at the bottom.

In a second method, the buoy is placed over the side and the placing vessel streams out the line behind it until the desired length of payout is attained. Then the anchor and bottom gear are attached to the line and dropped overboard. As the anchor plunges to the bottom the buoy moves toward the ship. When the bottom is reached, the anchorage is in place. A rule-of-thumb method of positioning a buoy by this method has been developed by Scripps Institution of Oceanography (Isaacs, 1963). The placing vessel proceeds a distance past the bottom position equivalent to one-third the calculated bottom depth, and at this point drops the anchorage system. Deadweight anchors may be free-dropped without restraint if the anchor is such that it will not be damaged or cause damage to the lines. However, it might be advisable to slow the descent of a bottom implement assemblage that includes conventional anchors, such as LWT's. This may be done by using a drogue anchor in the line assembly, as discussed in paragraph 4-6.

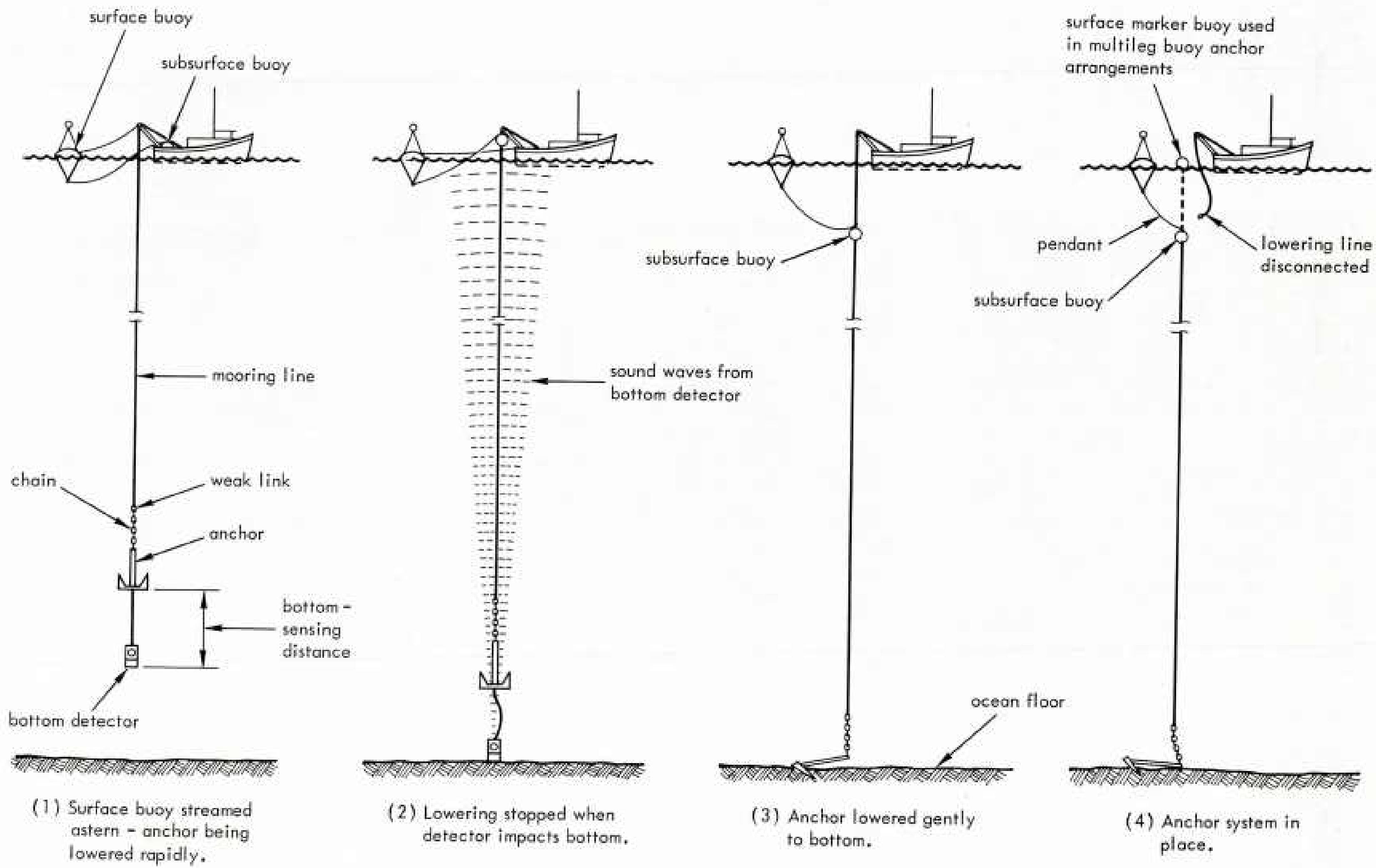

Figure 6-6. Installation sequence for two-buoy anchorage system.

In the third method the anchor is dropped with the bulk of the attachment line secured to it. The line pays out during the descent, from a container package termed the bale. By this method a long length of cable is not in motion when the object strikes the bottom. There are disadvantages to this method. First, the distance to the bottom must be known quite accurately to assure the correct amount of line being in the bale. Otherwise, an excess of line will be in the container package at moment of impact, or more serious, a premature runout of line will occur that would prevent the object from reaching the bottom. Premature runout of line may also severely damage attachments at the surface through force of impact. A second disadvantage of this method is that the bale becomes excessively bulky as cable size and length increase. At present, practical sizes for bales are limited to 5/8-inch cable in lengths to about 7,000 feet.

Two types of bales have been developed, referred to as "dense packs" and "random packs" (Huthsing, 1963). The dense pack results in a smaller, more compact bale, but the random pack tends to pay out line more uniformly. In both packs, a twist in the cable is made for each lay so no torque will exist on payout. The cable is maintained in position in the bale by a heavy foam that hardens after application, yet permits payout with minimum resistance. Development work is continuing with the cable bales at a number of private and government laboratories, including the Naval Civil Engineering Laboratory.

6-16. Embedment.

Embedment of bottom implements in the ocean floor is the means by which they attain their fixity and holding power. Accomplishing reliable embedment and controlling it to prescribed tolerance form a critical problem for designers and constructors.

6-17. Dragging. Dragging a conventional anchor is the primary method presently used for embedment. As noted in paragraph 3-2, conventional anchors must be dragged by a near-horizontal force to cause them to embed and develop holding capacity. An uplift component near 5 degrees or greater tends to cause the anchor to rise and lose some of its holding capacity (Towne, 1961). However, application of the requisite horizontal force at great depths requires excessive gear, and it is difficult if not impossible to sense the amount of movement and depth of embedment achieved.

Therefore, the current procedure is to predetermine the amount of tension desired in the connecting apparatus during installation and then to drag the anchor until this amount of tension is achieved. Next, the tension on the line is kept within established maximum and minimum limits until installation is complete. Thereafter, it can be deduced by performance of the moor whether or not the anchor is embedded as desired. As a rule, in the absence of surveillance it cannot be known for certain that the anchor is embedded and not snagged on an outcropping of rock or other impediment.

6-18. Drilling. Capability in drilling, a prerequisite to the placement of piles in the deep ocean floor, has been undergoing development since the inauguration of offshore oil exploration by the oil companies. Early experiments in shallow coring consisted of jetting in tubular casing, using water flow under relatively high pressure, often to depths of several hundred feet into the ocean bottom. This process, summarized here from a report by Global Marine Exploration (1964), used a continuous pipe running from above the surface of the ocean, with hydraulic flow from high-pressure pumps pumping through the inside of the pipe, opening up a surface hole ahead of the pipe as it was lowered. By contrast, a present normal method of drilling into the ocean floor is shown in Figure 6-7. The drill bit is weighted with drill collars for proper bit pressure and one or more spline-type "bumper subs" above the drill collar to allow for normal vertical heave of the surface vessel. With proper weight above the drill bit, a straight vertical hole can be drilled to depths of 100 feet or more to a vertical tolerance of less than 2 degrees. The hole is drilled using forced circulation of sea water which will remove most rock and sediment from the bottom of the hole, carrying it up and depositing it around the edges of the hole at the top and creating a crater effect there.

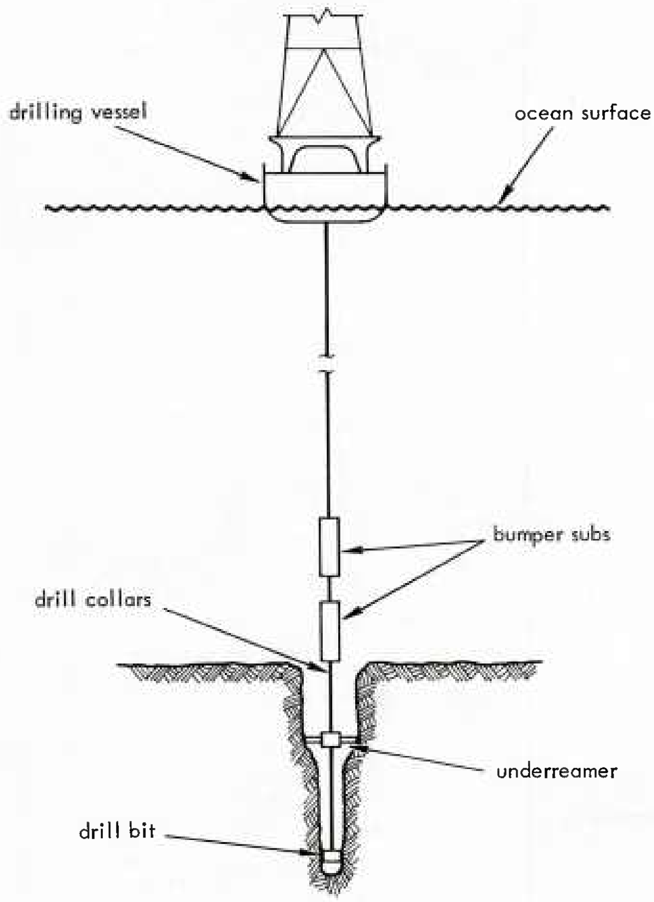

Figure 6-7. Weighted drill-bit method of drilling hole for piling.

Piling has been installed by welding a used bit at the bottom end of the pile and rotating the pile as if it were a drill pipe. In this procedure, the hole is drilled to the depth of the pile, the cement is pumped and the attachment at the top of the pile (usually a J-slot or screwed connection) is disconnected. An accepted procedure is to drill a hole with a normal small-diameter drill pipe, strip the piling over the drill pipe as shown in Figure 6-8, insert the piling into the hole for fit and then retract it. Next, the hole is filled with cement slurry pumped through the drill pipe, the piling is lowered into the slurry, and the drill pipe and bit are retracted. In the latter technique, it is not necessary to rotate the pile, which complicates the problem of pile attachment to anchor chain or wire line.

Theoretically, the mentioned techniques should permit installation of drilled-in piling in any depth of water up to the limit of preset practical use of drill pipe (about 25,000 feet). From a practical standpoint a more reasonable depth limitation would be the water-depth range of available television systems. Although present drilling techniques permit drilling a hole to great depths, it is still almost impossible to ascertain "by feel" whether the piling is actually in the hole. This means that visual observation of the setting of the piling in the hole is necessary. Television can in some cases be rigged to provide this visual coverage.

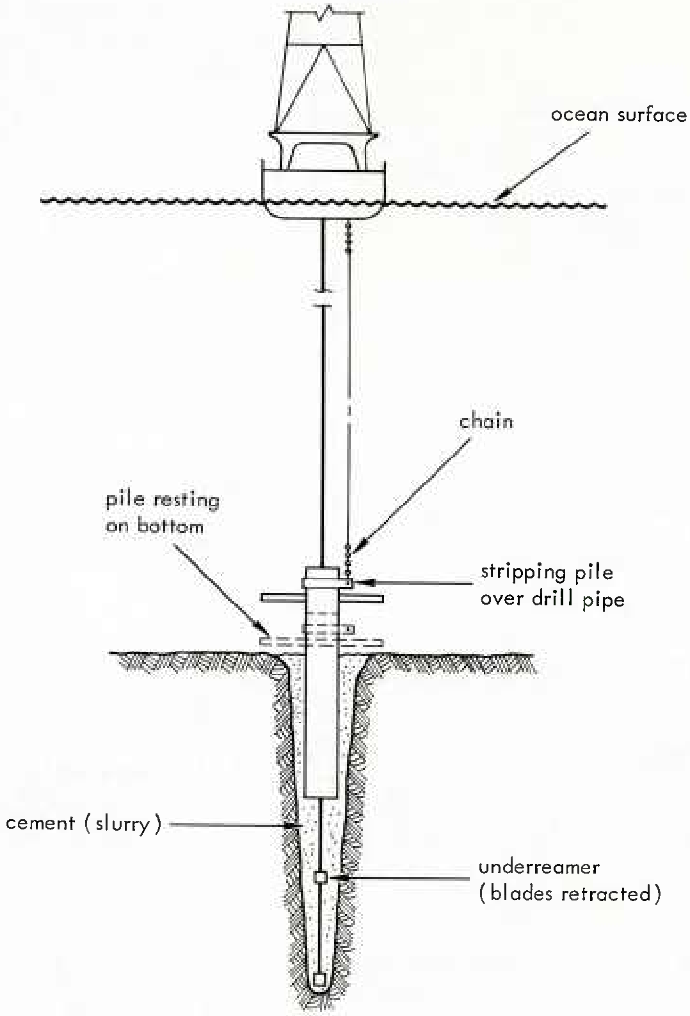

Figure 6-8. Pile-stripping method of setting piling.

During the trials for Project MOHOLE, Phase I, a pile and base, approximately 90 feet long, was drilled in 3,200 feet of water. However, the pile was not cemented for reasons of convenience. A procedure closely associated with drilling in of piles is the driving of piles. The difficulty and expense of driving piles increase rapidly with depth. Despite difficulties, the possibility of driving piles in truly deep waters (below 1,000 feet) is being given serious consideration. The use of explosives is one obvious special driving method that is being tried. Other schemes submitted for consideration include the utilization of the extreme ambient sea pressure. For example, potential energy at great depths would be stored by some means such as vacuum chambers and released under controlled conditions to activate hammers or pistons or to drive mechanisms. Driving by equipment capable of sustained repeated blows is a possibility. At this writing, however, no known driving procedure in water deeper than 1,000 feet has been tried except for the isolated case of propellant-embedment anchors.

6-19. Grouting. Grouting is a means of fusing a pile to the surrounding ocean bottom medium. The following information concerning it is summarized from a report by Global Marine (1964). To accomplish grouting, the top portion of the hole, jetted or drilled, is cased with conventional oil-field well casing, cemented in place by cement injected at the base of the hole, forcing the cement up outside of the casing and forming a bond between the side wall of the hole and the casing. Only minor problems are experienced in the sloughing off of the cement underwater as long as it is pumped from the bottom of the hole and forced upward. Experience in the last 15 years has provided no evidence of a tendency for the cement to spall, crack, or exfoliate because of underwater environment. Cement is mixed with fresh water or salt water to an approximate mixture of 10 parts cement and 8 parts water by volume. It should be well mixed with a power agitator, pumped quickly, and the piling should be set within 60 minutes of the pumping of the cement. Within 4 hours the cement will have set enough to make the piling difficult, if not impossible, to move. The addition of calcium chloride to the mix can decrease the setting time to about 60 minutes. Grout has been poured and laboratory tested under conditions of 200-foot-depth salt water. It is not known what effect very high pressure has on the mix.

A conservative estimate of the vertical holding power of cemented piling (smooth surface steel) would be based on a shear value between grout and steel of 75 pounds per square inch of steel surface. In the event that the bottom shear strength of soil is less than this figure (when considering the larger diameter and roughness factor), the shear strength between grout and soil would govern.

6-20. Recovery.

The capability to recover portions of anchorage systems is highly desirable. Many present buoy installations support instrument packages that must be retrieved. Others mark the location of, and are attached to, specimens on the ocean floor that are intended for recovery. For contemplated long-term complex anchorage systems, recovery capability is valuable for replacement and maintenance purposes.

Currently, the process of recovering depends on locating, attaching to, and effecting a clean, sure separation at, the desired point. Eventually, if replacement of parts becomes practical, a means of maintaining continuity in the system during withdrawal of portions of it will be necessary. None of these operations has yet been perfected to a high degree of reliability.

One significant series of experiments relating to recovery operations in deep water is that made by the U. S. Naval Civil Engineering Laboratory in connection with attempts to retrieve submersible test units (STU's) from various sites on the ocean floor. Jones (1964) describes the techniques and methods used which to date have resulted in the recovery of one STU from a depth of about 5,400 feet 4 months after its placement. Operations have included use of actuating coded acoustic-command separation devices, and grappling.

6-21. TECHNIQUES.

Deep ocean buoys, anchored or free-floating, may be hazards to navigation. They should be identifiable and distinguishable from buoys employed as aids to navigation. Also, they need to be locatable and/or trackable. Consequently, proper markings and other means of identification are essential.

6-22. Markings and Signals.

The Inter-Governmental Maritime Consultative Organization and the International Association of Lighthouse Authorities have submitted to various nations a joint proposal for the marking and lighting of oceanographic buoys in order to: (1) prevent collisions between ships and buoys; (2) simplify the detection and identification of oceanographic buoys and distinguish oceanographic buoys from aids to navigation (Tindle, 1964).

It is proposed that oceanographic buoys carry, for night location, lights of a flashing type, clearly distinct from those used on navigational buoys and other aids to navigation. The following specifications (see Appendix B) are recommended for such lights: (1) color: bluish-white of high intensity, corresponding to light of a xenon discharge tube; (2) repetition of signal rate: short periods of quick flashes of 15 to 18 seconds, the whole cycle being no less than 20 seconds. The possibility of using a constant white light on floating buoys of experimental nature or for a short duration is not excluded, provided that buoys are small and are not dangerous to navigation.

It is further proposed that for daytime location and identification, buoys should be painted in distinctive colors that present the least possibility of confusion with the colors used to mark aids to navigation and similar objects. Thus, fluorescent yellow and red in wide stripes (vertical for anchored, horizontal for free-floating stations) are recommended. For aid in radar detection and tracking, it is proposed that buoys be fitted with radar reflectors unless they are of such size and configuration as to be good radar targets. If so fitted, the reflectors should be as high above the sea as possible. As to sound signals, when fog bells or fog horns are fitted, care should be taken to ensure that the sound emitted is not confused with that emitted by devices giving navigational warnings.

The Third Session of the Inter-Governmental Oceanographic Commission (IOC), held in June 1964, adopted the Inter-Governmental Maritime Consultive Organization proposals outlined above (see Appendix B for further details) and recommended that IOC's 51 member nations including the United States adopt and implement the rules proposed. The IOC also took steps to form a working group to study the problem of fixed oceanographic stations, including the legal status of such stations (Beaufort, 1964).

Achievement of the adequate means of identification is a design problem for each buoy installation. Ideal solutions for all installations may not be possible. Power requirements for lighting, durability of paints for day markings, areas required for color markings, and the limitations of radar reflectors present problems not yet completely solved.

6-23. Locating and Tracking.

Locating and tracking buoys present both short- and long-range problems.

6-24. Visual Aids. Visual aids are important in overcoming the short-range problems because, once a locator is in the general area of a buoy, final contact is made by sight. Shipboard sightings are seldom over 2 miles by day and 10 miles at night. Brightly colored targets with two reflectors and flashing strobe lights are necessary to achieve even these modest ranges. For day marks, projected areas should be at least 2 feet above the surface to contribute to effectiveness. Minimum projected area above this height should be 15 square feet if feasible. For many buoys this area will be incompatible with buoy size and purpose. Fluorescent pigments are advisable for the coloring. These are available in both paints and films. In general, fluorescent films are longer lived than paints and are easy to apply and replace. Films with cold-weather pressure-sensitive adhesives have held up well on steel buoys for as long as 2 years. The height of the strobe light on a buoy is not as critical as that for the color target, especially for ranges under 5 miles. For slightly greater effectiveness, however, increased height will help (Tindle, 1964).

6-25. Radar. Radar can be used to augment visual aids in locating buoys. It can increase the daytime range of contacting buoys to 5 to 7 miles, but has several limitations and disadvantages. Most oceanographic buoys are not economically or practically adaptive to active radar equipment. Passive radar reflectors on buoys give consistently poor results, chiefly because radar waves are greatly attenuated near the ocean surface. The effectiveness of a radar reflector on buoys, within limits, gains as the fourth power of the height (Tindle, 1964).

6-26. Sound Signals. Sound signals are another possible short-range aid in locating oceanographic buoys. At the current stage of development it is believed they are impractical because of their expense, weight and unreliability. Wave-actuated fog signals, bells, gongs, and whistles are heavy and generally perform the worst when most needed.

6-27. Radio. Radio appears to offer the best potential for long-range locating and tracking of buoys. However, monitoring the position of an anchored buoy or tracking the movements of many buoys in large-scale drift experiments is a particularly difficult and expensive operation with present technology. Woods Hole Oceanographic Institution has employed several radio beacon systems successfully (Walden, 1964). In one, a small 2.5-watt beacon with transmitter completely transistorized can be keyed at a slow rate by a solid state keyer or by a printed circuit disk containing the call signal. A marine fiber-glass whip antenna operating in the 2 to 3 megacycle band is used with the transmitter. With Navy-type, DAV automatic direction finders, signals from this beacon transmitter can be picked up from 50 to 60 miles away and are strong enough to be used for homing purposes. A longer transistorized transmitter with power output of 40 watts, designed at Woods Hole Oceanographic Institution (WHOI), has been used in conjunction with telemetry work. A bearing sufficiently accurate for homing at about 200 miles can be obtained.

Another system has been developed at WHOI that has proved particularly effective. It utilizes the retransmission of Consolan signals on command. Consolan is a radio signal system operated by the Federal Aviation Authority primarily for aircraft service from two stations on the East Coast and one station on the West Coast. It is an adaptation of the European Console and Sonne Systems (Walden, 1964). This system is equally effective for marine coverage in establishing reliable azimuth bearings for distances up to 1,200 miles. Positions of buoys can be determined within an accuracy of about 5 miles at a range of 600 miles. The Consolan System affords coverage of about a million square miles of ocean.

PART 7
NEW CONCEPTS AND DEVELOPMENTS

7-1. GENERAL.

As deep-ocean construction activities expand, new materials, new equipment, and new principles are constantly being discovered. Often their profitable application in areas other than those for which originally intended is not immediately recognized. Similarly, materials, equipment, and principles that have been known for some time are not immediately seen as being adaptable and useful in other than proven ways. Examples of new concepts and developments are here offered in the hope that they may suggest possible solutions to constructors of deep ocean anchorages.

7-2. EXAMPLES.

7-3. Oceanographic Buoy.

Most oceanographic buoys to date have been of modest size. The maximum dimension has usually been 15 feet or less. However, according to Devereaux (1964), a 40-foot diameter, 5,000-pound buoy with discus hull configuration, known as Ocean Data Station, is being developed for anchorage in depths to 30,000 feet (Figures 7-1 and 7-2). It is to be unmanned and remain on station for one year unattended.

Development is proceeding with these basic guidelines; (1) the buoy is to have at least 1,000 sensors for acquisition of oceanographic and atmospheric data; (2) all sensors are to be scanned at least once each hour; (3) the buoy is to be capable of telemetering data stored from the sensors, upon command from a shore station as much as 2,500 miles distant, once every 6 hours; (4) all data is to be stored on board the buoy in a long-term memory for the recommended endurance of 1 year.

Fourteen different shapes were tested in a towing basin. Stability, low drag, and payload capability were the chief factors considered in selecting the discus shape. The discus does not show a preferred orientation to waves or current. Being symmetrical, it offers good potential for using the buoy hull as a sensor to measure surface-wave profiles and to obtain wave-directional power spectra. Fiber-glass-reinforced plastic was chosen for construction of the hull. When fully developed, this structure will be the prototype for a family of remote, data-gathering, telemetering buoys. The initial prototype was successfully launched in late 1964.

The anchorage system for the Ocean Data Station is significant because the size of the buoy is the greatest yet attempted for extreme depths, and the construction the most permanent. Under consideration are mooring lines to 2-1/2 inches in diameter. It is expected that these will have a parallel-filament construction for torsional balance and additional tensile strength, have a density of about 1, and contain one or more electrical conductors. The bottom point of the anchoring system is intended to act as a fail-safe element, absorbing excess forces by displacement of the anchor to avoid severance of the mooring lines. To achieve this objective, a length of destroyer chain might be used for the anchor.

A challenging problem is the swivel connecting the buoy to the mooring line. It must be electrically conducting and yet free-moving to preclude twisting and kinking of the line. Initially, for economy and less complexity, a single-point anchorage system was designed using a one-to-one slope of the line. For the future - when it is desired to hold other Ocean Data Stations rigidly on location - three-legged anchorages are contemplated.

7-4. Self-Reeling Submerged Float.

A modification of a submerged spherical buoy, which will pay out additional wire as soon as the design tension of the pendant is reached, has been operated (Isaacs, 1963). This self-reeling submerged float functions as shown in Figure 7-3. The surface line is wound around the large reel of diameter D_1 and the bridle is wound around two smaller reels of diameter D_s on opposite sides. All three spools have the same axis of rotation and are fixed relative to one another. When the tension in the pendant exceeds $(D_s/D_1) \times B$ (buoyance), the float winds down the bridle, releasing a length of wire D_1/D_s times the distance traveled until the stress in the pendant falls below $(D_s/D_1) \times B$, or the buoy is two-blocked against the bridle.

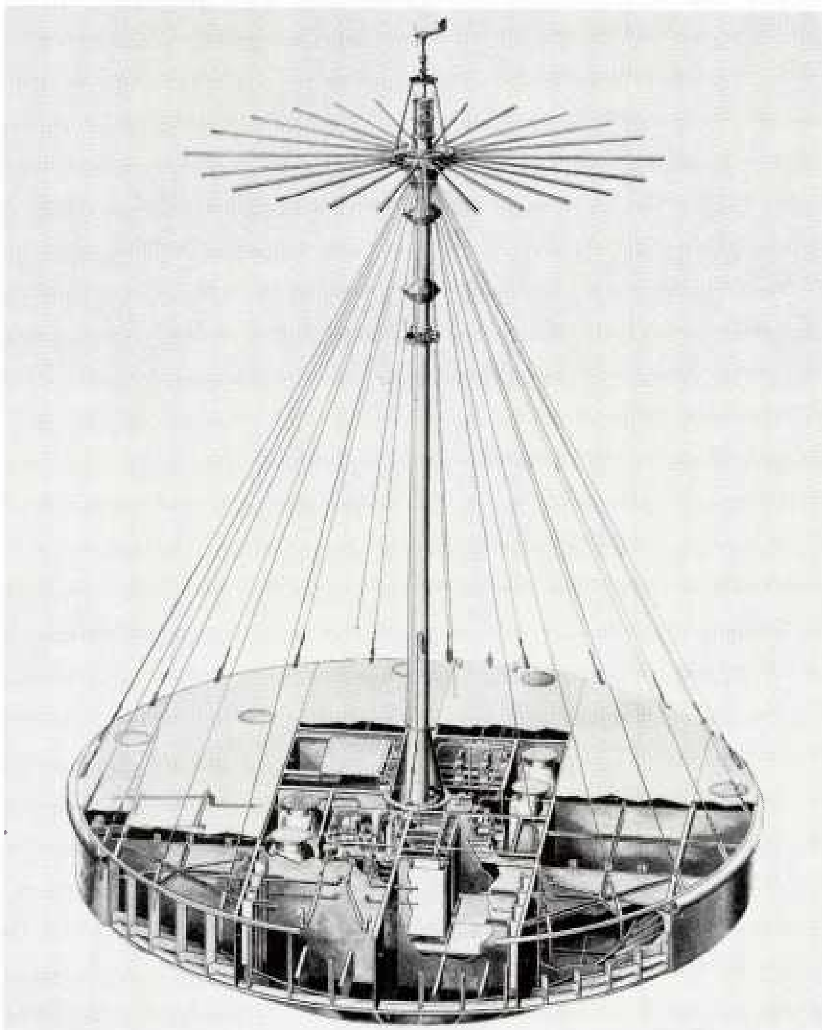

Figure 7-1. Oceanographic Data Station (40-foot diameter).

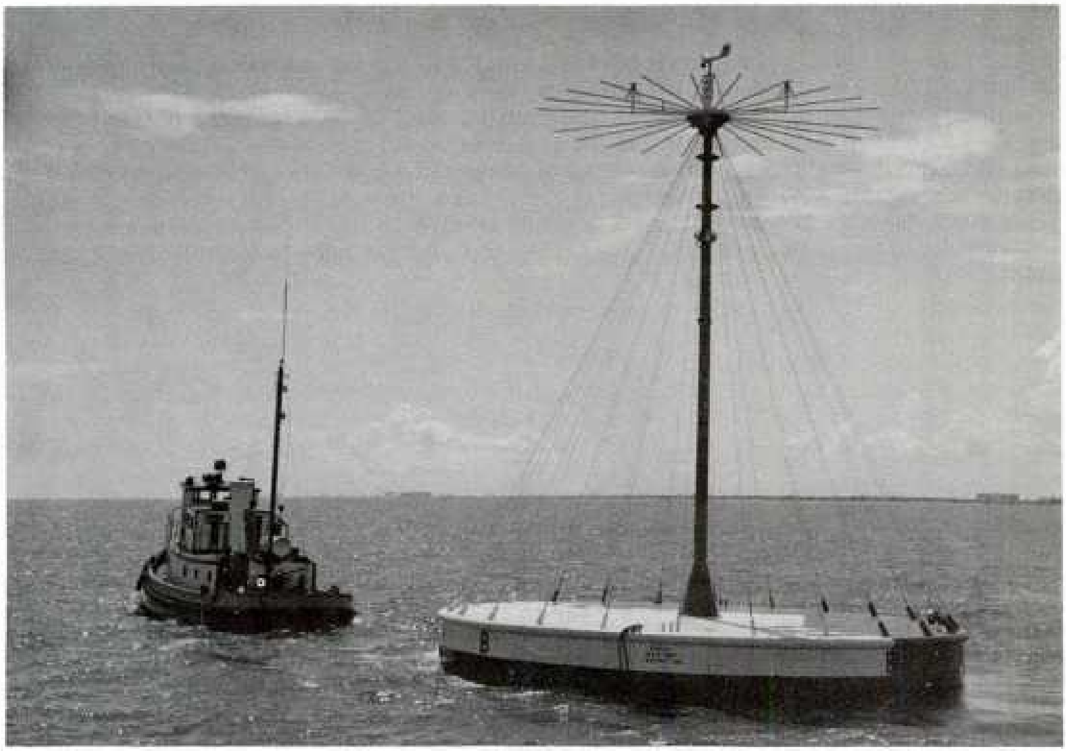

Figure 7-2. Oceanographic Data Station (40-foot diameter) being towed to sea.

The advantages this concept provides are: (1) the instrument line may be combined with the mooring line, eliminating the necessity for two lines over the side; (2) the instrument mooring line may be retrieved for inspection, servicing, or replacement by merely heaving in; and (3) the necessary additional scope to accommodate extreme sea conditions is provided, and a nearly vertical pendant line may be used, thus greatly reducing hazard from surface traffic.

This self-reeling float would normally be used in conjunction with an elastic pendant designed to accommodate the wave-induced displacements of the surface buoy. Therefore, the self-reeling float needs only to accommodate the larger deflection caused by extremes of wind and current.

7-5. Shock Mitigator.

A 1-inch round rope of a highly elastic gum-rubber material is reported to have been used as a shock mitigator with good success in a two-buoy taut-line anchorage system (Maddux, 1964). The material will elongate 300 percent safely, and in at least one instance has been submerged in an ocean environment for over a year without apparent adverse effect on its strength or efficiency. For use as a shock mitigator (Figure 7-4), the rope is inserted between the submerged and surface buoys. In the normal position of the two buoys the rope is elongated about 100 percent. The primary strength rope connecting the two buoys is attached to the elastic rope at intermediate points with generous slack provided by means of loops. Thus the elastic material develops a taut connection and still allows considerable motion before the main strength rope is brought into action to resist applied forces.

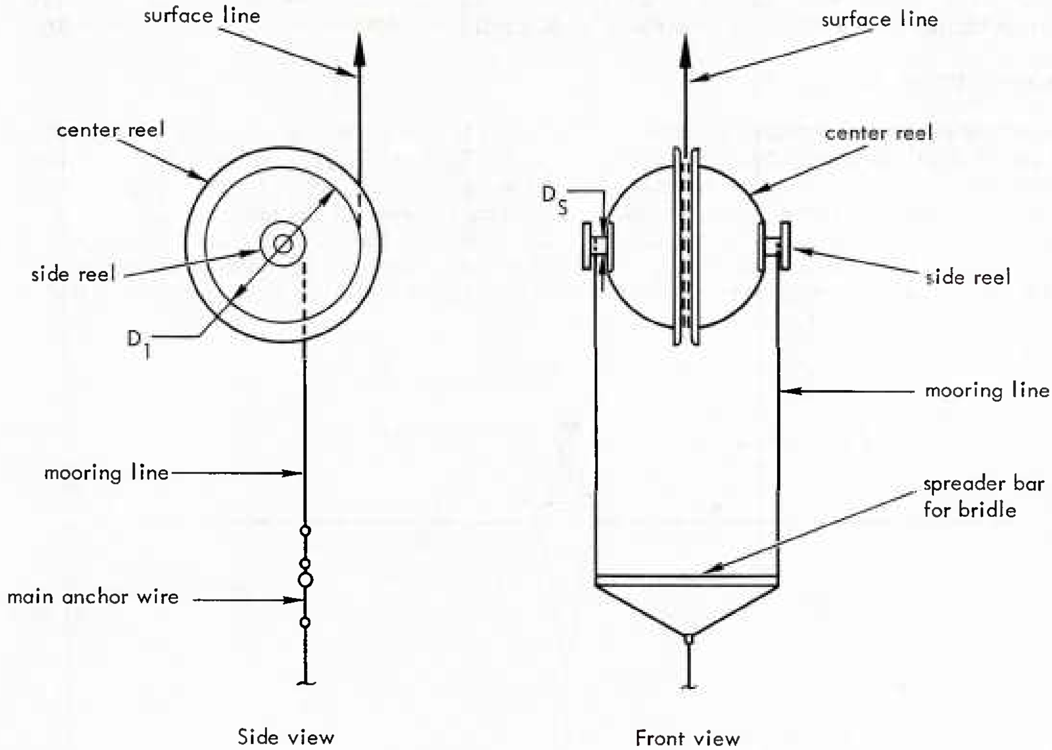

Figure 7-3. Self-reeling submerged float.

7-6. Buoy Stabilizer.

Stabilization of buoys or parts of buoys for the measuring, recording, and transmitting of data is often necessary for proper functioning. For example, in some kinds of measurements (e. g., wind fluctuations), the support of sensing elements in true upright position is essential. A buoy has been designed that carries a mast held upright by the aid of servomechanisms (Hasse, 1964). Vertical orientation is derived from a gyro. The gyro, servomotors, and gearings are built into a cylindrical container 80 centimeters in diameter and 86 centimeters high, which is carried by the buoy. Meteorological instruments and an accelerometer are stabilized, and enable, by means of twofold electronic integration, the calculation of height of waves, taking into account the dip of the buoy.

7-7. Deep-Descending Pressurized Buoy.

A buoy of simple construction, apparently capable of descending with a payload to the deepest parts of the ocean without collapsing, recently has been invented at the Naval Civil Engineering Laboratory (Beck, 1964a). This buoy, which can be constructed of various materials, uses a combination of gases and ambient ocean water to equalize inner and outer pressures as the buoy and its payload descent to the ocean floor (Figure 7-5). At a preset time interval, or by any of several other means, such as contact with the bottom or through the use of acoustic or electrical devices, a liquid gas expellant material is released and transforms to the gaseous state. The gas provides buoyancy sufficient to raise the buoy and payload to the surface. The buoy can be used as a free-acting unit or be captive and controlled from the surface. Though not yet fully tested, it appears to offer advantages in certain applications over the three pressurized-buoy types described in paragraph 1-21. Another deep-descending buoy employing a similar principle of operation is described by Stixrud (1964).

7-8. Echo-Sounding Equipment.

Echo-sounding equipment exists by which it is possible to determine the shape of towing cables as well as the depth to a sampling net (Baakus, 1956). This technique conceivably could prove a valuable tool in constructing and maintaining anchorages. Knowledge of the configurations of a moor leg at all times during placement is important because of the effect of the configuration on tension in the line and the direction of load at the anchor. Also, once the anchorage is in place, the echo-sounding technique could prove valuable in monitoring the configuration of the leg during varying load conditions, and thus determining conditions that could endanger the installation.

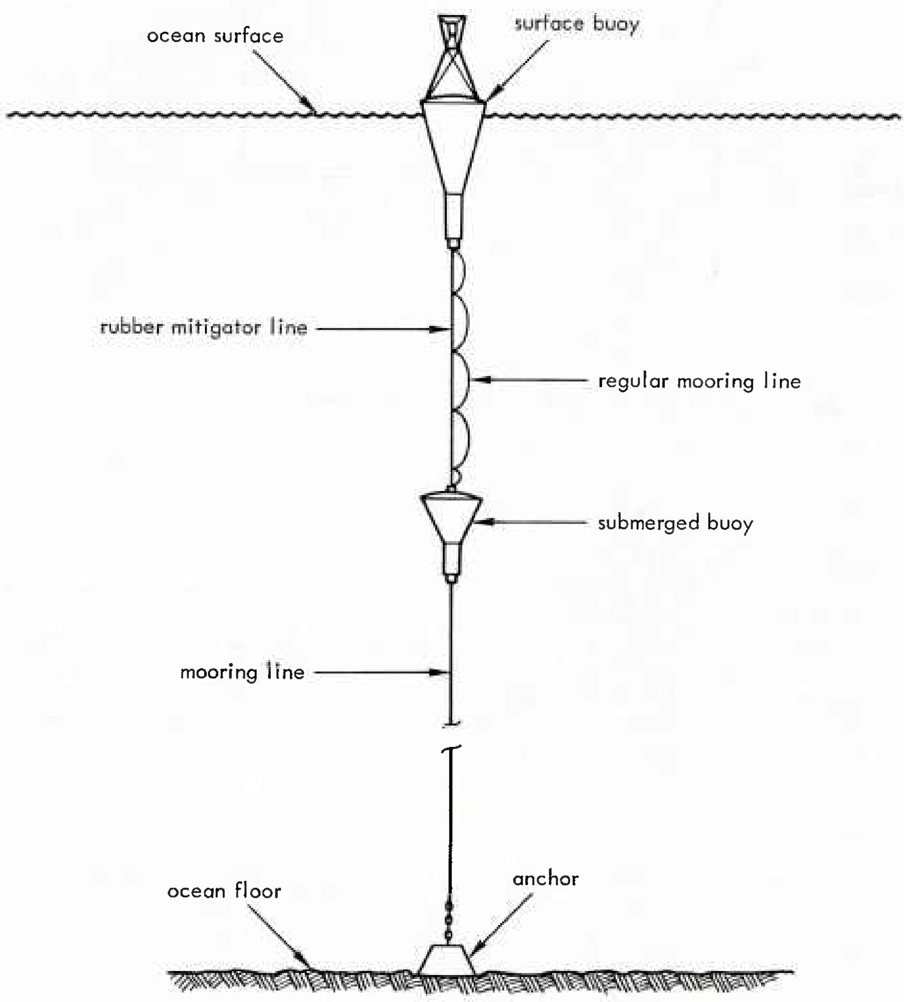

Figure 7-4. Elastic gum-rubber shock mitigator for two-buoy anchorage.

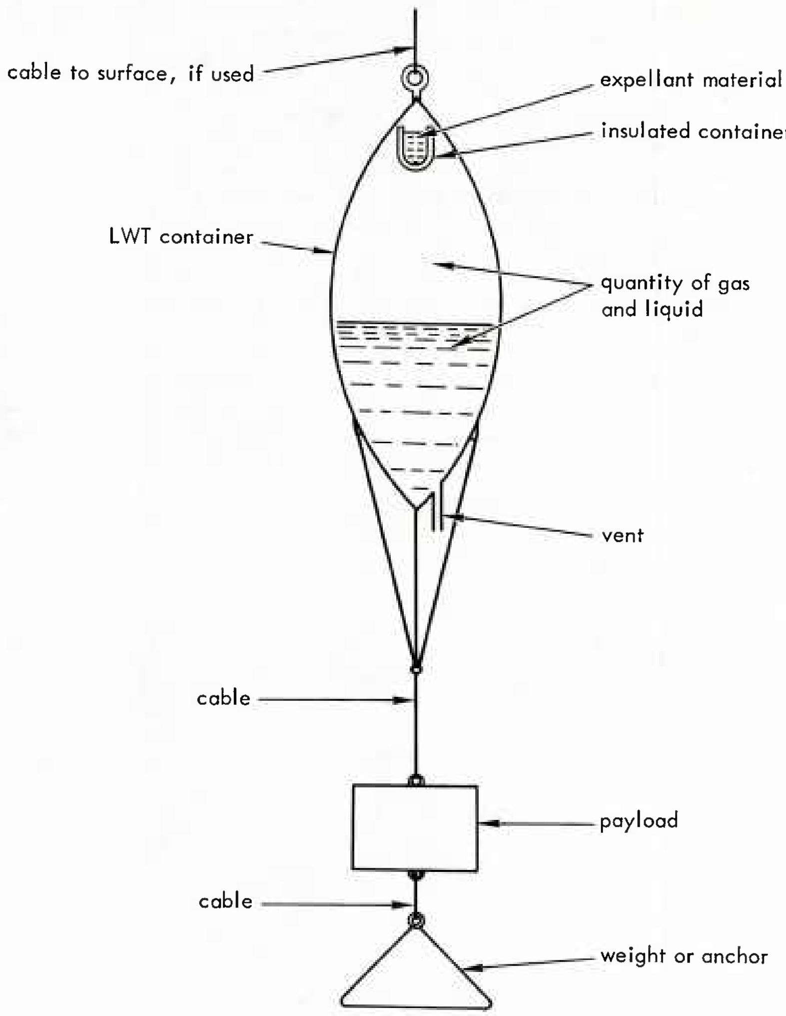

Figure 7-5. Deep-descending pressurized buoy.

7-9. Winching Machine.

A caterpillar-tractor-type winching machine for handling cable with instruments attached is under development for the Office of Naval Research (Bonde, 1962). This winch uses two parallel treads between which line and instruments pass. Pressures between the treads are controlled hydraulically. It is claimed that less likelihood of damage to anchor line and instruments results. This capability for handling lines without damage to appurtenances is advantageous because numerous attachments, including cathodic protection devices, often will be necessary in deep ocean activities.

7-10. Constant-Relationship Hoist.

A constant-relationship hoist is undergoing development at the U.S. Coastal Engineering Research Center. This unit is capable of transferring a 2-ton load between two vessels in rough seas. It accomplishes this by moving the load in sympathy with the deck of the receiving vessel until the transfer is completed. A separate line attached to the deck of the receiving vessel signals information to a computer-integrator unit which automatically operates the hoist to maintain constant relationship between the load and the receiving vessel. Ultimately, it is anticipated that loads up to 450 tons can be handled.

This device when operable may prove to be adaptable for use in lowering heavy components of deep-ocean anchorage systems. Setting heavy loads on the bottom without damaging the rope or the load has been a problem. The adaptation would have to include some means to accommodate the separate line and its attachment to the sea bottom.

7-11. Drilling Equipment.

A recent development which might be utilized to drill in piles on a wire line in the deep ocean is a deep-ocean coring tool developed by Global Marine Exploration Company for the National Science Foundation (Global Marine, 1964). This tool is lowered on a combination electrical and strength cable. The tool consists of a coring barrel and a submerged electric motor driving a pump. The pump takes suction on salt water and discharges the major portion of the flow through the barrel. A small amount of the discharge is diverted to two jets on torque arms to counteract the motor torque and keep the assembly from rotating.

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APPENDIX 7-A*

EXAMPLE OF SPAR BUOY FOR USE IN OCEAN RESEARCH

SPAR (Seagoing Platform for Acoustic Research) is a 354-foot, cigar-shaped vessel, 16 feet in diameter, to be operated with six-sevenths of its length submerged. Its purpose is to study the precise measurement of sound transmission and propagation through open sea water, and it requires two auxiliary vessels. The tender (Figure A-1, also Chapter 3, Figure 8-4) tows SPAR, provides electrical power and certain electronic signals through a 3,000-foot floating cable, and processes data. The other ship is the target vessel which transmits acoustic and RF signals to be received and compared by SPAR at ranges from 5 to 100 miles. The total SPAR "package" costs approximately $1 million.

SPAR displaces 1,370 tons in tow position and 1,720 tons when submerged vertically. Its unique shape is expected to provide a maximum heave velocity of 1 fps in sea state 4.

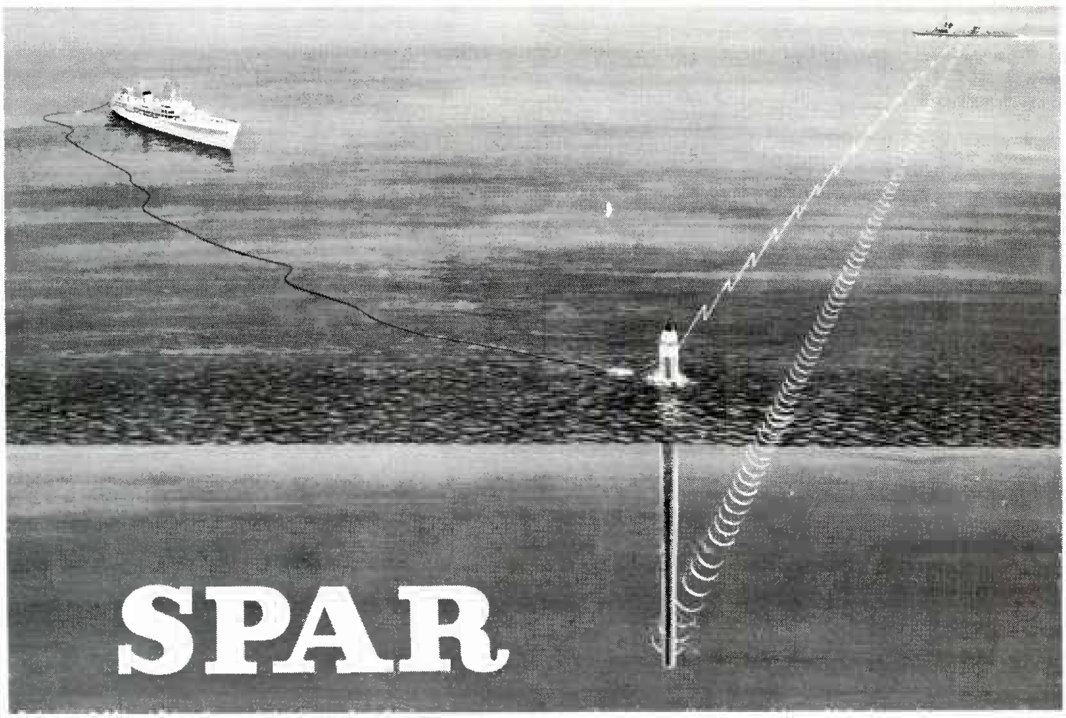

Figure A-1. SPAR (Seagoing Platform for Acoustic Research) with service-tender vessel and target ship. ©Undersea Technology, Compass Publications

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SPAR is constructed of rolled shell plating stiffened with T-beam longitudinals and transversals. It is subdivided by watertight bulkheads and tank decks into ballast, buoyancy, trim and stability, free-flooding, and equipment compartments (Figure A-2). The attitude of SPAR is controlled by flooding or blowing a tank at the stern. During the change of attitude, stability is maintained principally by shifting salt water ballast between two tanks. Eight small ballast tanks permit adjustment of trim in the vertical position. In addition there are six free-flooding tanks, open to the sea at all times. Liquid level meters and indicators are used in the flooding and erection cycle.

Four machinery spaces are all located in the forward end of the vessel; three of these are above the waterline when SPAR is in the vertical position. In the forward compartment are a 10 kw diesel generator for use when external power is not available, air compressors, and storage batteries all mounted on a trunnioned platform. The next compartment aft contains two UHF direction finder antennas and the analyzer for an optical twist-measuring device. (Naval Ordnance Laboratory engineers are looking for improvement in measurement of vessel twist, compared with performance of this equipment on FLIP). Next is the electronics compartment where the MK 19 Mod 3 gyrocompass, electronics instrument, and data recording equipment racks are trunnion mounted. The fourth compartment is the pump room and valve station. An instrument trunk is provided for future installation of deep-depth hydrophones.

A ventilation system furnishes automatic heating of the electronics compartment, pump room and machinery compartment, and automatic cooling of the electronics compartment. Emergency blowing of the erection tank is provided by a high-pressure air system. Equipment external to the shell of SPAR has been kept to a minimum to decrease the tendency for the vessel to weathercock, due to wind, in the vertical attitude. Hydrophone vents are located at the stern and 50 feet from the stern, extending 25 feet out from the centerline in each direction. Hydrophone mounting rails extend forward from the stern 200 feet.

The preliminary design for SPAR was done at the Naval Ordnance Laboratory, White Oak, Maryland, and the final design was by M. Rosenblatt and Sons, Naval Architects and Marine Engineers, of New York. Aerojet-General Shipyards, Incorporated, was awarded the contract for the construction of SPAR in May 1963, for a fixed price of $747, 277.

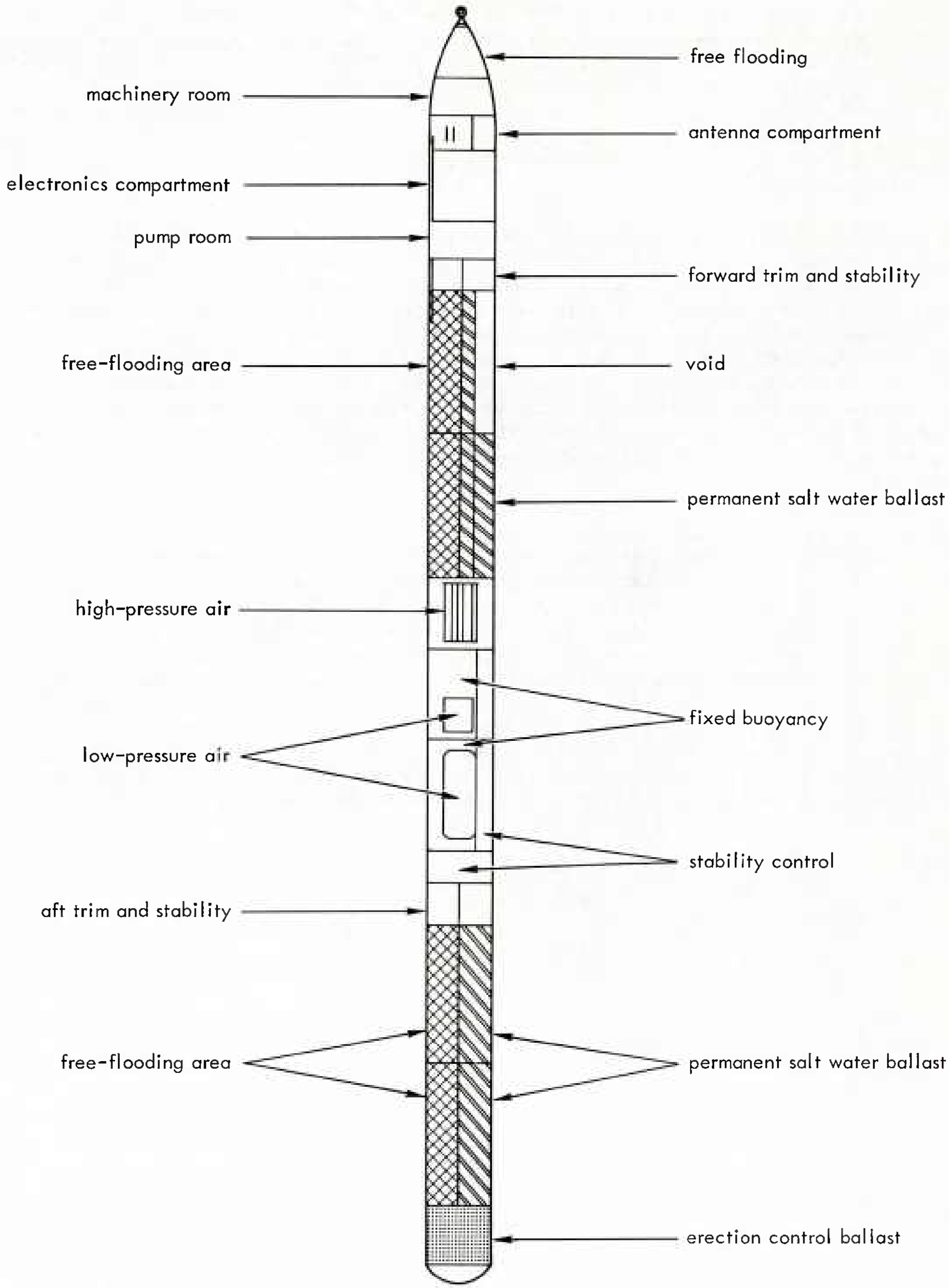

Figure A-2. Sectional view of SPAR showing compartmented inner construction.

APPENDIX 7-B

RULES ON THE MARKING AND IDENTIFICATION OF FIXED OCEANOGRAPHIC STATION

(Recommended by Inter-Governmental Oceanographic Commission to Member Nations - June 1964)

Rule 1. Classification of existing types of oceanographic stations:

(a) Craft which, owing to their size, material, and construction, can cause and/or receive damage through collision. Such craft carry personnel and may have moderately heavy equipment on board. They may be operating at any distance from the coast, either anchored or not.

(b) Permanent structures embedded in the sea floor and rising above the sea surface (masts and platforms), manned and unmanned, generally within a short distance of the coast.

(c) Equipment which, owing to size, material, and construction, is less likely to cause damage through a collision. However, it may receive damage or can foul a propeller or rudder or fishing gear. Such equipment is not expected to carry personnel and it may be anchored at any distance from the coast.

(d) Free-floating equipment generally small in size and operating either independently or in the proximity of research vessels or craft of the type described in 1(a). Such equipment can be carried away for long distances, drifting with the currents.

Rule 2.

(a) Craft of type described in Rule 1(a), since they appear to satisfy the requirements of the definition of "vessel," should be treated as vessels and comply with the appropriate Rules of the International Regulations for Preventing Collisions at Sea in force.

(b) Permanent structures of the type described in Rule 1(b) should be considered generally as aids to navigation. Their light characteristics and other navigational aids should be adopted in consultation with the country, or countries, most concerned. Their position should be marked on the charts and information should be promulgated as required in Rule 2(g) below.

(c) Oceanographic stations of the types described in Rules 1(c) and 1(d) should carry at night identification lights of a flashing type clearly distinct from those used on navigational buoys and other aids to navigation. The following specifications are recommended:

(i) Color: white-bluish, high-intensity, corresponding to the light of xenon discharge tube.

(ii) Repetition rate: short period of quick flashes of a few seconds' duration (2 to 5 seconds) followed by a longer period of darkness (15 to 18 seconds), the whole cycle no less than 20 seconds.

NOTE: The possibility of using a constant white light on floating buoys of experimental or short-duration nature should not be excluded provided that those buoys are small and do not represent any danger to navigation.

(d) For easy identification, oceanographic stations of the types described in Rules 1(c) and 1(d) should be painted in standard colors presenting the least danger of confusion with the markings being used for the various aids to navigation or other purposes. Fluorescent yellow and red in wide stripes (vertical for anchored stations and horizontal for free-floating ones) should be recommended.

(e) The following equipment should be fitted on the types of stations described in full in 1(c) and 1(d) as far as practicable:

(i) Radar reflectors: unless buoys are of such size and configuration as to be good radar targets. If fitted, radar reflectors should be as high above the sea surface as possible.

(ii) Fog bells or fog horns: when fitted, care should be taken to ensure that the sound emitted is not such as to be confused with the sound emitted by similar navigational warning devices.

(f) The requirements specified above should not exclude the possibility of installing on these stations special radio transmitters for direction-finding purposes.

(g) Information concerning oceanographic stations which represent a danger to or an aid to navigation (position, size, safe distances to be observed and other important characteristics) should be promulgated to mariners through the usual channels (notices to mariners, radio warnings, etc.) Member States might also use other means to ensure the widest possible promulgation of such information, especially to fishing interests of the countries concerned.

(h) Member States should use numbers or other inscriptions on the stations to facilitate identification and to discourage unauthorized handling of such stations.

(i) Care should be taken by authorities operating such stations to avoid obstructing fairways used by shipping.

APPENDIX 7-C

A DESIGN PROCEDURE FOR MOORING SMALL DEVICES

It is believed that the following design procedure for mooring buoys and other small devices in depths from 100 to 3,000 fathoms, excerpted by permission from a report prepared by Isaacs et al. (1963) for Scripps Institution of Oceanography, is as authoritative a one as currently exists.

A. System Design

The design of mooring must stem from a knowledge of the physical forces of the environment acting upon the components in a geometry determined by the same interaction. Hence the design cannot be uniquely expressed as any simple function of the parameters. Rather, the various components may be provisionally selected by simplified criteria, the geometry of the assemblage examined, and adjustments made. A workable method for doing this is outlined. The design is carried out step by step as follows:

1. The mean or model surface current, vertical current profile, wind velocity, and depth of water are measured or estimated. Estimates are also made of extremes of surface current, wind, and wave height. The magnitudes of all these phenomena may depend on the season and on the length of time that the mooring will be in place.

2. The wind drag and the water drag on the surface unit are calculated. The wind drag on the vessel or skiff may be computed for any impact angle once the drag area has been determined. The wind drag area of the hull, the superstructure, the masts, and the like above the water line may be taken from the vessel's prints, or perhaps estimated. A convenient formula for computing the wind drag is

$$F = KAV^2$$

where F = force in pounds

K = constant = 0.0025 (a value as high as 0.004 is often used for more complicated shapes such as that of a large ship)

A = wind drag area of vessel in square feet

V = speed of wind in miles per hour

Conversion factors for velocity in different units are given in Table C-I.

Table C-I. Velocity Conversion Factors

Velocity	Statute Mile/hour	Knots	Ft/sec	Ft/min
1 statute mile/hour	1	0.868	1.47	88.0
1 knot	1.15	1	1.69	101
1 ft/sec	0.682	0.592	1	60

The water drag or hull resistance of a vessel is broadly considered in two parts: (1) the surface or skin resistance and (2) the wave-making resistance. The surface resistance is computed by using the conventional formula

$$R_s = f_s A V_k^{1.83}$$

where R_s = surface resistance in pounds

f_s = a coefficient of friction, assumed here as 0.01

A = area in square feet of wetted surface

V_k = current or water speed in knots

The wave-making resistance is not normally computed, but for our purpose here it may be assumed to approximate 30 percent of the total hull resistance. For ships of usual design at moderate speeds (as when anchored in a current), this approximation is frequently used.

3. The weight and the horizontal drag of the submerged elements are calculated. The chief components are the mooring and the submerged float, which is selected to have a net buoyancy equal to about 60 percent of the ultimate strength of the wire.

When the current structure (vertical distribution of current) at the mooring site is known or assumed, the drag force on the mooring wire and components may be computed from the formula

$$F = C_d A V^2$$

where F = drag force in pounds

C_d = a coefficient of drag which may vary, for example, from 0.3 to 1.5, but which, for first approximations, we assume to be 1.1

A = area of wire in square feet

V = current speed in feet per second

If instrument strings are suspended over the side, the added drag may be computed by using the above formula. If the current is not uniform from surface to bottom, the total force will be obtained by appropriate integration, or forces may be applied as a series of point loadings for several increments of depth.

4. The angles of the wire at the submerged float and at the anchor are estimated from the relationships:

γ_1 = wire angle from the vertical at the submerged float

F_{H_1} = total horizontal drag of submerged float and array above it

B = buoyancy of submerged float

$$\gamma_1 = \tan^{-1}\left(\frac{F_{H_1}}{B}\right)$$

γ_2 = wire angle from the vertical at the submerged float

W = weight of wire in water

F_{H_2} = total horizontal drag on entire system below submerged float

Then
$$\gamma_2 = \tan^{-1}\left(\frac{F_{H_1} + F_{H_2}}{B - W}\right)$$

5. A preliminary estimate of dip and excursion may now be made by fitting between these two angles a circular arc having a length equal to the length of cable between the submerged float and the anchor (Figure C-1) as follows:

$$D = \frac{360L}{2\pi\left(\gamma_2 - \gamma_1\right)}\left(\sin\gamma_2 - \sin\gamma_1\right) - L$$

where D = dip

L = length of wire between submerged float and anchor;

and
$$E = \frac{360L}{2\pi\left(\gamma_2 - \gamma_1\right)}\left(\cos\gamma_1 - \cos\gamma_2\right)$$

where E = excursion

The excursion is somewhat overestimated by this procedure and the dip is somewhat underestimated.

6. If the estimates of dip and excursion are satisfactory, the design may proceed. If they are too large, buoyancy may be increased moderately, say by 10 percent, or other adjustments may be made. If these measures do not suffice, the size or the strength of the wire selected must be increased and the calculation must be repeated. This increase may be judged by selecting a wire with a strength/drag ratio that is larger

than the first trial by the ratio of the calculated excursion (E_1) to the desired excursion (E_2). That is, $R_2 = R_1 (E_1/E_2)$, where R_1 and R_2 are the strength/drag ratios, respectively, of the first and the second trial wires. As the recalculated float and other parameters will scale proportionally to R, this second trial should be adequate. Note that simply increasing the size of the wire increases R.

7. The geometry of the mooring should now be analyzed with greater exactitude. This may be done with the aid of Pode's cable function tables or by the graphic method described later. In this computation it may be advisable to include factors that have previously been neglected, such as:

   Water drag on the mooring pennant.

   Water and wind drag on auxiliary floats.

   Water drag on any instrument strings.

   Buoyancy of auxiliary floats.

   Buoyancy of the surface float (instrument skiff, etc).

8. As soon as the design is satisfactory from the standpoint of excursion and dip, the minimum anchor weight is determined by the criteria discussed subsequently under "Anchors."

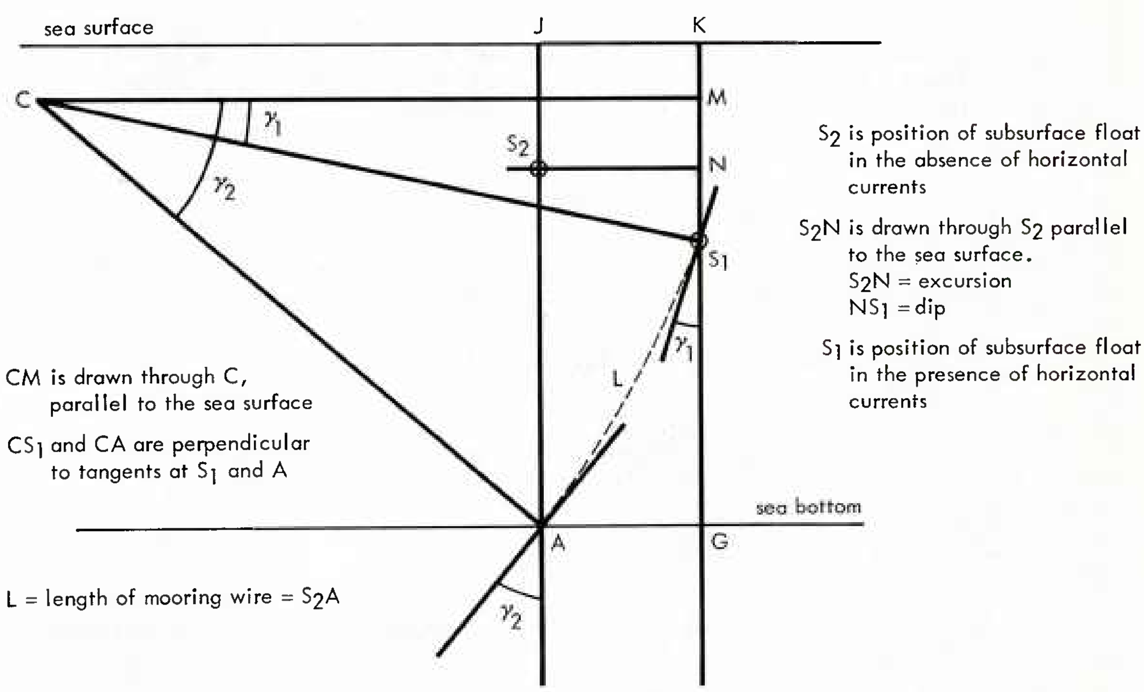

Figure C-1. Excursion and dip of submerged float.

9. The pendant length and characteristics are now chosen to afford satisfactory performance in combers, as explained earlier. This is carried out by determining the geometry of the mooring under highest expected wind stress without current stress. Then, assuming that the submerged buoy remains fixed, the pendant is extended horizontally to 20 percent of L_0 of the critical wave. The force increase should be such that $(V_t + V_u)/2 = C_0/12$, where V_t is the velocity of the surface float under a force equal to the wind stress, V_u is the velocity of the surface float under the increased force of the extended pendant, and C_0 is the phase velocity of the wave.

10. The calculation in step 9 is repeated, using the configuration of the mooring for highest wind and current stress, and the stress is examined when the pendant is extended horizontally 20 percent of L_0 as before.

11. The lift induced by the pendant may now be entered into the calculation, if necessary.

In the final design several additional requirements have been found advisable.

Two provisions against failure of the submerged float are: (1) the surface float is given additional buoyancy adequate to support both the cable and the submerged float if water-filled, and (2) the main mooring cable is terminated at a distance above the anchor somewhat greater than the distance the submerged float would sink. In this lowest portion we use a suitable flexible wire rope, such as 3/16-inch, 3 by 19 improved plow steel. Aircraft cord, which is more susceptible to kinking and abrasion, is not suitable. The flexible rope is used to prevent the brittle mooring wire from dragging on the bottom in case of flooding of the submerged float.

B. Basic Computations for Drag Forces on the Mooring

The force exerted by a fluid flowing past a submerged object at a steady rate may be expressed as

$$F = C_D\left(\frac{W}{2g}\right)AU^2$$

where F is the fluid force, usually referred to as the total drag force (a combination of skin drag and form drag); C_D is a dimensionless drag coefficient; W is the specific weight of the fluid (weight per unit volume); g is the acceleration of gravity; A is the projected area of the object that intercepts the flow; and U is the undisturbed speed of the fluid. Strictly speaking, this equation applies only when the object is small compared with the dimensions of the fluid, far from the boundaries, and only when the undisturbed velocity of the fluid is uniform as well as steady. To conform with standard engineering practice, the English system of units is adopted in the presentation here. Thus, with W in pounds per cubic feet, g in feet per second squared (32.2), A in square feet, and U in feet per second, the value of F from the preceding equation will be in pounds. For sea water, W is about 64 pounds per cubic foot, so that W/2g is just about unity, thus simplifying the expression for the drag force as follows:

$$F = C_D AU^2$$

The drag coefficient C_D depends upon the shape and the roughness of the object and on the Reynolds number Re, associated with the flow. The Reynolds number is defined by

$$Re = \frac{UD}{v}$$

where D is the effective diameter of the object and v is the kinematic viscosity of the fluid. For water at 70°F, v is about 10^{-5} per square feet per second. Consequently, the following expression for Re is valid for problems dealing with flow of water around obstacles:

$$Re = 10^5 UD$$

If the submerged object is a circular cylinder or a sphere, then the effective diameter is the actual diameter. The values of drag coefficients for smooth circular cylinders of large length-to-diameter ratio, with the axis perpendicular to the flow, are presented in Table C-II prepared from data in a book by Rouse (1946). The ranges of Reynolds numbers represented are those encountered in most engineering problems. The values have been obtained from laboratory studies under conditions of steady (unaccelerated) flow.

The results of these laboratory experiments indicate that there exists a critical value of Reynolds number above which the regime of disturbed flow around the object is changed abruptly, leading to a decrease of C_D. Not much information is available for roughened cylinders; however, the indications are that: (1) for lower than critical Re the value of C_D is essentially unchanged; (2) for higher than critical Re the value of C_D is larger than that for a smooth surface; and (3) the value of the critical Re is somewhat reduced. A brief series of tests which the authors of this report conducted indicates that the drag of twisted wires is somewhat less at higher Reynolds numbers, possibly because of spoiling.

The value of C_D for a long flat plate of width D is about 2.0 (or about 6 times the value of C_D for a cylinder at high Reynolds numbers), and apparently has no critical value of Re in the range 3×10^3 to 10^6.

C. Steps in the Graphic Solution of a Deep-Mooring Configuration

Step 1. Measure or assume velocity distribution.

Step 2. Calculate V^2.

Step 3. Calculate drag frontal area of wire.

Step 4. Calculate drag of various components.

Step 5. Calculate weight in water F_V of various components.

Step 6. Sum weight, F_V and drag F_H (individually).

Step 7. Calculate wire angle $= \arctan \Sigma F_H / \Sigma F_V$

The wire shape may now be derived graphically by constructing successive force-vector diagrams starting at the anchor and proceeding upward as shown in Table C-III and Figure C-2. Note that Figure C-2 shows the graphic steps of only the lower three segments into which the mooring has been divided. Force diagrams and configurations are simultaneously constructed.

Table C-II. Drag Coefficients

Reynolds number (Re)	Drag coefficient (C_D)
10^3 to 10^4	1.0
10^4 to 2×10^4	1.2
Larger than 5×10^5	0.33

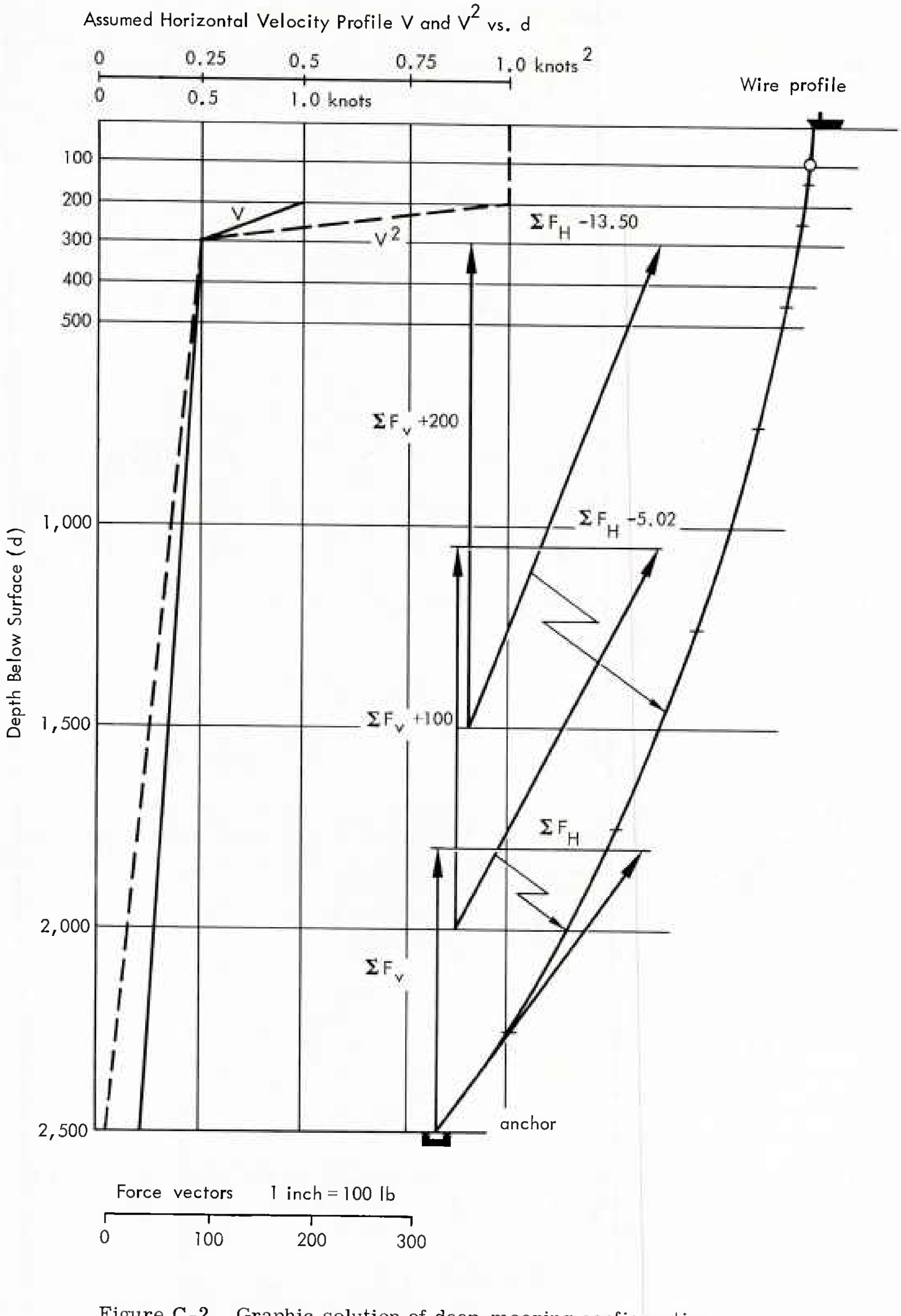

Figure C-2. Graphic solution of deep-mooring configuration.

Table C-III. Sample Calculation of Forces

(Sample calculations for a mooring using 2,500 fathoms of 0.120-inch piano wire which weighs 500 pounds and has a breaking strength of 3,190 pounds. As the anchor for this mooring must weigh a minimum of 536 pounds or a maximum of 1,414 pounds, an anchor weighing from 700 to 900 pounds would be a reasonable choice.)

Depth (fathoms)	V (knots)	V (ft/sec)	V^2 $\left(ft^2/sec^2\right)$	Area $\left(ft^2\right)$	F_H (lb)	ΣF_H (lb)	F_v (lb)	ΣF_v (lb)
Skiff					90.0			
Buoy					10.0	100.0	-780	-780
100-200	1.00	1.69	2.86	6	18.9	118.9	40	-740
200-300	0.750	1.27	1.62	6	10.7	129.6	20	-720
300-500	0.486	0.818	0.669	12	8.9	138.5	40	-680
500-1,000	0.439	0.742	0.550	30	18.2	156.7	100	-580
1,000-1,500	0.370	0.626	0.392	30	13.0	169.7	100	-480
1,500-2,000	0.302	0.512	0.262	30	8.6	178.3	100	-380
2,000-2,500 (bottom)	0.234	0.397	0.158	30	5.0	183.3	100	-280

D. Calculation of Restoring Forces on a Surface Float

Imagine a pendant having floats equally spaced along its length. Let the slope of the pendant at the submerged float of the taut mooring be $\theta 1$, and the slope at the skiff be zero. Then as an approximation we may consider that at each line float the slope of the pendant changes by the same amount $\Delta\theta$, and that it is perfectly straight between floats. Then

$$\Delta\theta = \left(\frac{1}{n}\right)\theta$$

and the slope above the mth float (Figure C-3) is expressed by

$$\theta m = \theta m\text{-}1 - \Delta\theta$$

If F_B is the buoyancy of a float, then the force it exerts in a direction at equal angles to the two pendant segments above and below it is expressed by

$$F_b = \cos\left(\theta m\text{-}1 - \frac{1}{2}\Delta\theta\right) F_B$$

Therefore, the force in the direction of the pendant segment above the float and in the downward sense is expressed by

$$F_p = \frac{1/2\,F_b}{\sin 1/2\,\Delta\theta}$$

Although it is clear that the figure assumed for the array is imaginary and never, in fact, occurs, it is sufficient to use as a basis for calculating the magnitude of the effects of a buoyant pendant.

The force parallel to the sea surface is expressed by

$$\begin{aligned} F_h &= F_p \cos \left[90^\circ - \left(\theta_{m-1} - \Delta\theta\right)\right] \\ &= F_p \sin \left(\theta_{m-1} - \Delta\theta\right) \end{aligned}$$

For a 300-foot pendant with scope 2.0 and ten equally spaced floats having a buoyancy of 4.5 pounds each, if the angle at the submerged buoy is 60 degrees, the total force in a horizontal direction is

$$\begin{aligned} \Sigma F_h &= 43.3\,\Sigma \cos \left(\theta_{m-1} - \frac{1}{2}\Delta\theta\right) \\ &= 43.3 \times 3.2 = 138 \text{ lb} \end{aligned}$$

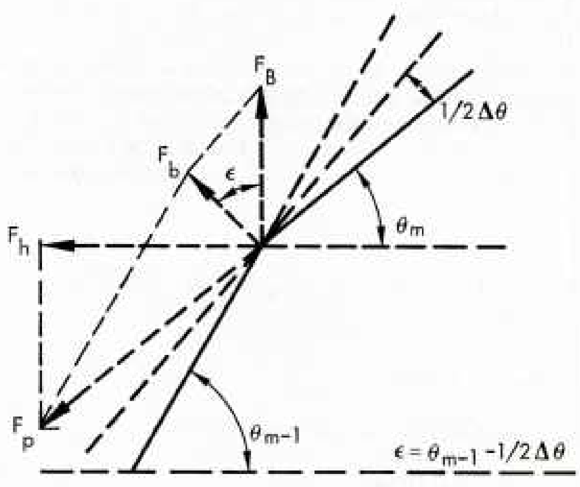

Figure C-3. Restoring forces on a pendant.

The initial horizontal restoring velocity at the skiff may then be calculated, using the following assumed form drag areas:

A half-inch pendant reaching to 150 ft (1/2 x 1/12 x 150)	6.3 sq ft
Ten floats	2.8
A vertical instrument line with instruments	3.0
Equivalent form drag area of skiff (20 x 0.01)	0.2
	12.3 sq ft

$$V_0\sqrt{\frac{2 \times 138}{1.2 \times 12.3 \times 2}} = 3 \text{ ft per second}$$

which exceeds the requirement of 2.5 feet per second set by a hypothetical storm wave 25 feet high.

This result is not very sensitive to changes in the figure of the pendant except under two conditions. The first is the improbable condition that combers might occur when there is little wind or surface current. The second is that the pendant is stretched so that θm at every float is less than 30°. In this instance, however, the elastic stretching of the pendant rapidly increases the restoring force, as already noted. When the skiff is being driven by the cascading comber, its bow is deep in the water and $C_D \approx 1.0$. When it surmounts or reaches the terminus of the comber, it floats higher, especially at the bow, and $C_D \approx 0.01$. There is thus a large effective force available to stretch the pendant, of which a small proportion is sufficient, when added to the buoyancy of the floats, to make up the required restoring force.

E. Anchors

High-density anchors are desirable because their small dimensions for a given weight permit handling without excessively long booms or davits. Also, their high rate of lowering in water allows a mooring to be laid in a short time, thus avoiding drifting off station.

Various kinds of anchors have been used. Some have been solid steel cubes with pad eyes welded on top and bottom, and some have been ordinary railroad-car wheels. As moorings increase in size and complexity, a more sophisticated design of anchor will be required if the size of the mooring wire is to be kept at a minimum. For Scripps installations, gravity anchors have been designed so that the net vertical reaction against the bottom is equal to at least 1.4 times the sum of the expected horizontal forces. Or,

$$W_A + W_w - B = 1.4F_H \text{ (Figure C-4)}$$

where W_A = weight in sea water of anchor

W_w = weight in sea water of wire below submerged float

B = buoyancy of submerged float

F_H = horizontal component of forces at the anchor

$= F_m \cos\theta$, where F_m is the tension on the mooring wire

This has led to satisfactory performance on a relatively flat bottom. For a bottom with a slope ϕ, the frictional force F_f required may be expressed as

$$F_f = 0.7\left(W_A - T\right)\cos\phi$$

where
$$T = B - W_w = F_m \sin\theta$$

For equilibrium the sum of forces F acting parallel to the slope must equal zero, or

$$F = T\sin\phi - W_A\sin\phi - F_H\cos\phi + 0.7\left(W_A - T\right)\cos\phi = 0$$

$$W_A - T = \frac{F_H}{0.7 - \tan\phi}$$

With these assumptions a simple gravity anchor becomes impractical on bottoms with slopes exceeding about 20 degrees, and anchors with hooks, flukes, or grapnels must be used. Unless other considerations are overriding, it is best to anchor moorings in flat areas. Small-scale bottom features may be ignored to the extent that the displacement of the system caused by an anchor gradually sliding down to a local bow is negligible. On extensive steep slopes it is difficult to anchor a mooring at a selected depth, and such sites are doubly undesirable.

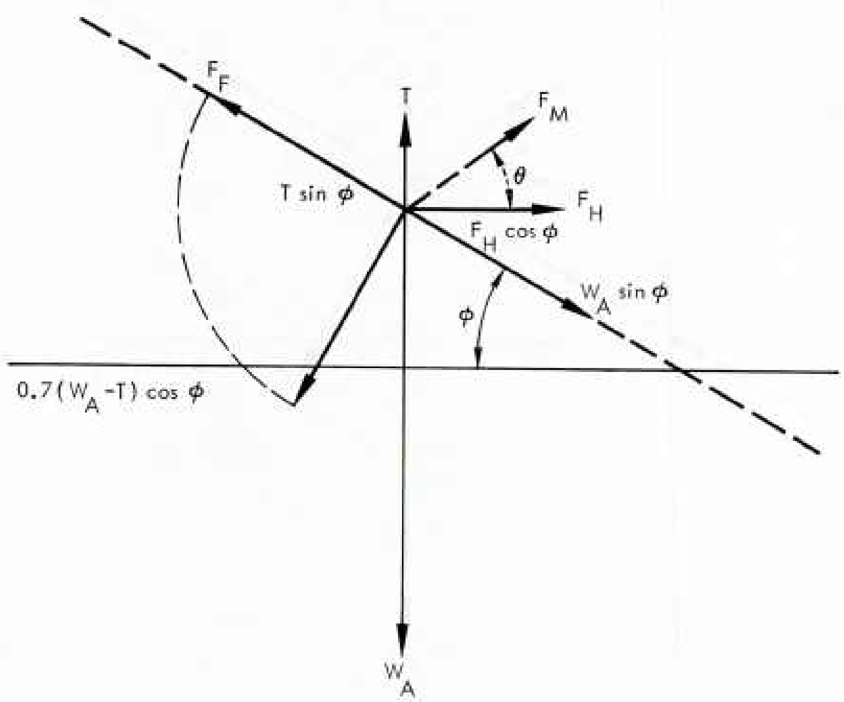

Figure C-4. Forces on anchor on sloping bottom.

APPENDIX 7-D

SUGGESTED LIST OF SALIENT SPECIFICATION ITEMS FOR DESIGNERS OF BUOY ANCHORAGE SYSTEMS

Nature and size or size range of the buoys to be moored.

Location (geographical) of the moor.

Allowable motions (or function of the moor, which would require the definition of allowable motions, including stability).

Environment; may or may not be specified in enough detail to allow the definition of forces and loadings on the mooring. These will include wind velocities, wave height, depth of water and hydrological features, bottom composition, etc., and the fluctuations of these site characteristics. If these are not specified, they must be derived or assumed before the design of a mooring can be undertaken.

Design life of the moor.

Restrictions as to clear space for passage in or around the mooring.

Fail-safe features desired.

Minimum wire rope sizes.

Desired installation date.

Cost range.

In situ servicing requirements.

Retrieval servicing or moor-removal requirements.

Collision and accident protection features.

APPENDIX 7-E
BIBLIOGRAPHY ON CATENARY PROBLEMS

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APPENDIX 7-F
INSTALLATION OF TOTO II MOOR

In addition to two LCM work boats and the YFNB-12, the following ships were assigned to the TOTO II installation:

USS RECOVERY (ARS-43)

USS KIOWA (ATF-72)

USS LUISENO (ATF-156)

USS PAIUTE (ATF-159)

USS SALISH (ATA-187)

USS STALLION (ATA-193)

In summary, the RECOVERY maintained position at the center of the array, receiving the span wires as passed, and completing the tensioning process of the moor. The ATF vessels laid the individual legs and the ATA vessels provided towing assistance to the RECOVERY and to the ATF vessels. The YFNB-12, moored at High Cay, provided logistic support; and the two LCM workboats provided towing assistance, tended the buoys, and transferred personnel and equipment between vessels. Various phases of the installation procedure are depicted in Figures F-1 through F-4 and outlined below, as excerpted from a report prepared for the Navy by Hydrospace (1964).

1. The installation commenced with the 150-degree leg. The KIOWA, with ATA assistance, maintained station in a 500-foot anchorage circle, bow heading away from the center of the moor. The anchor and four shots of chain were dropped from the stern roller, and payout of the wire rope began.

2. After 3,550 feet of wire rope were paid out, the desired junction point in the leg was reached. The rope was stopped off, cut, and both ends socketed. The ground ring and fittings were inserted, and the remaining wire rope on the drum of the KIOWA became the vertical riser to the intermediate buoy. The LUISENO then moved up, bow heading toward the center of the array, and passed the bitter end of the upper catenary to the KIOWA. This was attached to the ground ring, aboard the KIOWA, and the LUISENO then moved 500 feet toward the center of the array, paying out wire rope at a rate sufficient to keep it under slight tension only.

3. From their respective stations, the two ships next paid out wire rope simultaneously until the anchor bottomed. At this point the LUISENO continued to pay out rope, while proceeding toward the center of the array. The KIOWA also paid out additional rope, following the ground ring as it moved toward the center, in order to keep the riser as nearly vertical as possible. During this process, the KIOWA moved approximately 3,500 feet toward the center of the array.

4. With the full scope of the vertical riser deployed, and the KIOWA on the approximate station of the intermediate buoy, the LUISENO increased the line tension to 20,000 pounds and laid additional rope to a total scope of 7,500 feet. At this point, the LUISENO stopped off the wire rope and connected a strain gage to the carpenter stopper.

5. An intermediate buoy was next brought up to the KIOWA by an LCM; and the main vertical riser aboard the KIOWA was cut, socketed, and a ground ring installed. The chain riser from the buoy was then passed to the KIOWA and attached to the ground ring. The buoy-retrieving pendant was also attached to the ground ring, and was eased out by the towing engine until the strain on the leg was taken up by the buoy. The upper end of the retrieving pendant was then attached to the buoy, and the KIOWA proceeded to High Cay to be reloaded from the YFNB-12.

6. With the KIOWA out of the area, and the intermediate buoy installed, the LUISENO increased the line tension to 40,000 pounds, noting position carefully. This tension was held for 15 minutes to set the anchor and straighten the anchor leg, with position reading available to indicate any dragging of the anchor. The line tension was then reduced to 20,000 pounds, and the wire rope was cut, socketed, and connected to a ground ring and fittings.

7. The RECOVERY next streamed approximately 500 feet of span wire, and passed the loose end to the LUISENO. An LCM brought up the main buoy for the leg, which was installed as in step 5 above, with the span wire also connected to the ground ring. The LUISENO then proceeded to High Cay for reloading, while the RECOVERY paid out an additional 1,500 feet of span wire as it proceeded to its station at the center of the array, maintaining a line tension of 10,000 pounds.

   During the installation of the 150-degree leg, as above, the ATF-159 towed the buoys from High Cay to the installation site; and the ATA vessels provided assistance as required. The 30-degree and 270-degree legs were installed in a similar manner, with the three ATF vessels exchanging roles as necessary. At this point, all three span wires were secured on board the RECOVERY by carpenter stoppers and the vessel itself was tied to two of the main buoys by nylon bow lines in order to maintain position against the strain in the system. (The span wire from the 150-degree leg passed through the stern roller; the span wire from the 30-degree leg passed inboard around a norman pin on the starboard side, tending forward; and the span wire from the 270-degree leg passed inboard around a norman pin on the port side, also tending forward.)

8. The RECOVERY warped itself into position at the exact center of the array by varying the length and tension of the span wires. The span wires were then inhauled to a uniform horizontal tension of 10,000 pounds, cut, and socketed. The slack portions of the 30-degree and 270-degree span wires were next passed outboard and returned inboard through the stern roller.

9. The three span wires were connected to a flounder plate, while an LCM brought up the center buoy. The buoy riser was next passed through the stern roller and connected to the flounder plate. The retrieving pendant was also joined to the flounder plate, and its other end connected to the towing engine. (During this process, the LCM held the center buoy clear of the RECOVERY.)

10. At this point, the retrieving pendant was taken in by the towing engine until the strain in the system was transferred to this link. The SALISH and the STALLION next attached nylon lines to the main buoys off the bow of the RECOVERY to support these buoys against the tension in the bow lines from the RECOVERY. The RECOVERY then released the span wires and the buoy riser, holding only the retrieving pendant. By inhauling on the nylon bow lines, the RECOVERY moved forward, paying out the pendant slowly, allowing the entire array to settle into place. By connecting the now-loose end of the retrieving pendant to the buoy, the installation was complete and all vessels cleared the area.

The kinds and quantities of material used in anchorage installations are indicative of the costs and operational requirements for emplacing them. A tentative but not all-inclusive bill of material for the TOTO II moor is included in this appendix following the illustrations.

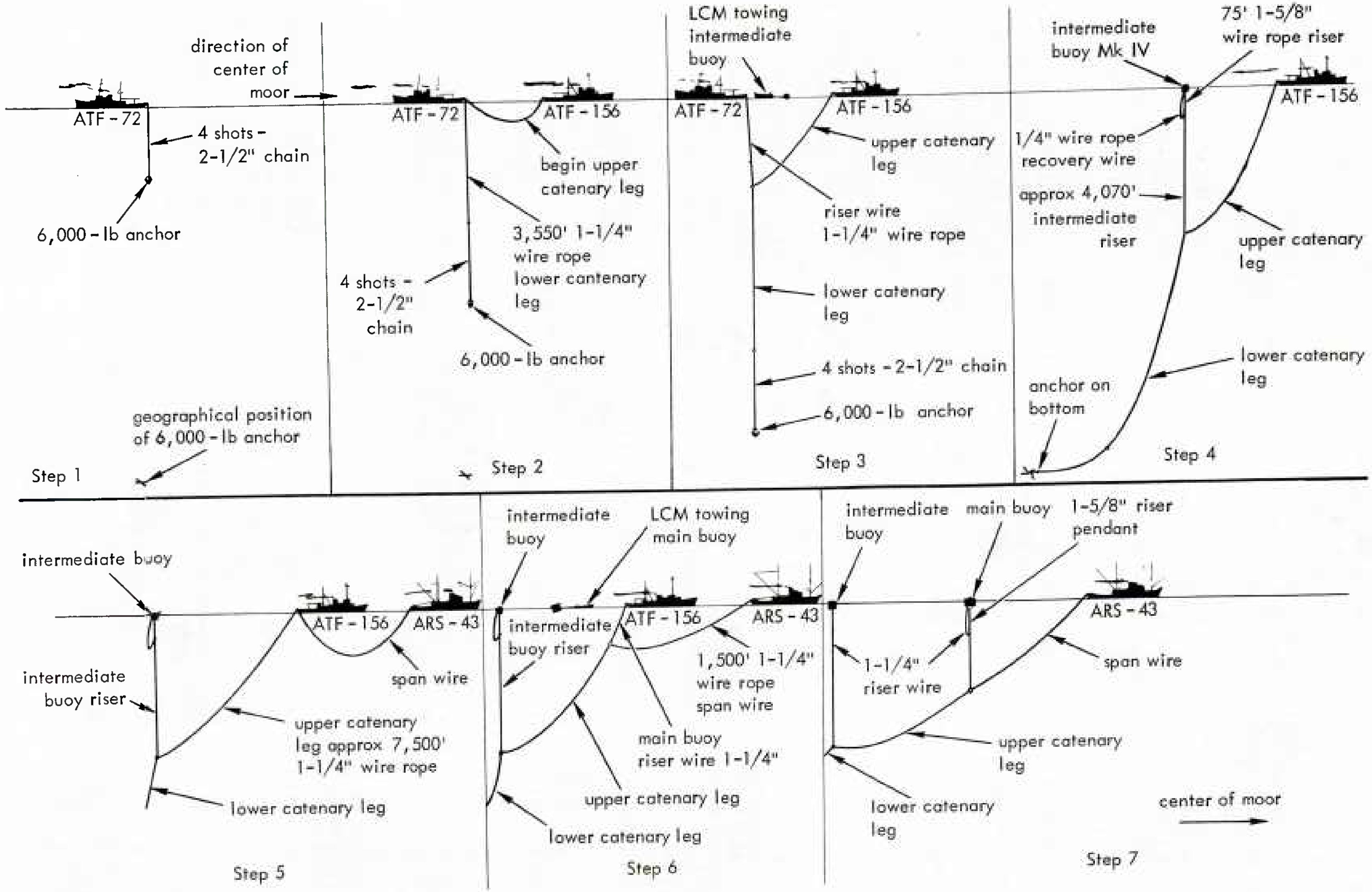


Figure F-1. Procedure for installing TOTO II mooring legs.

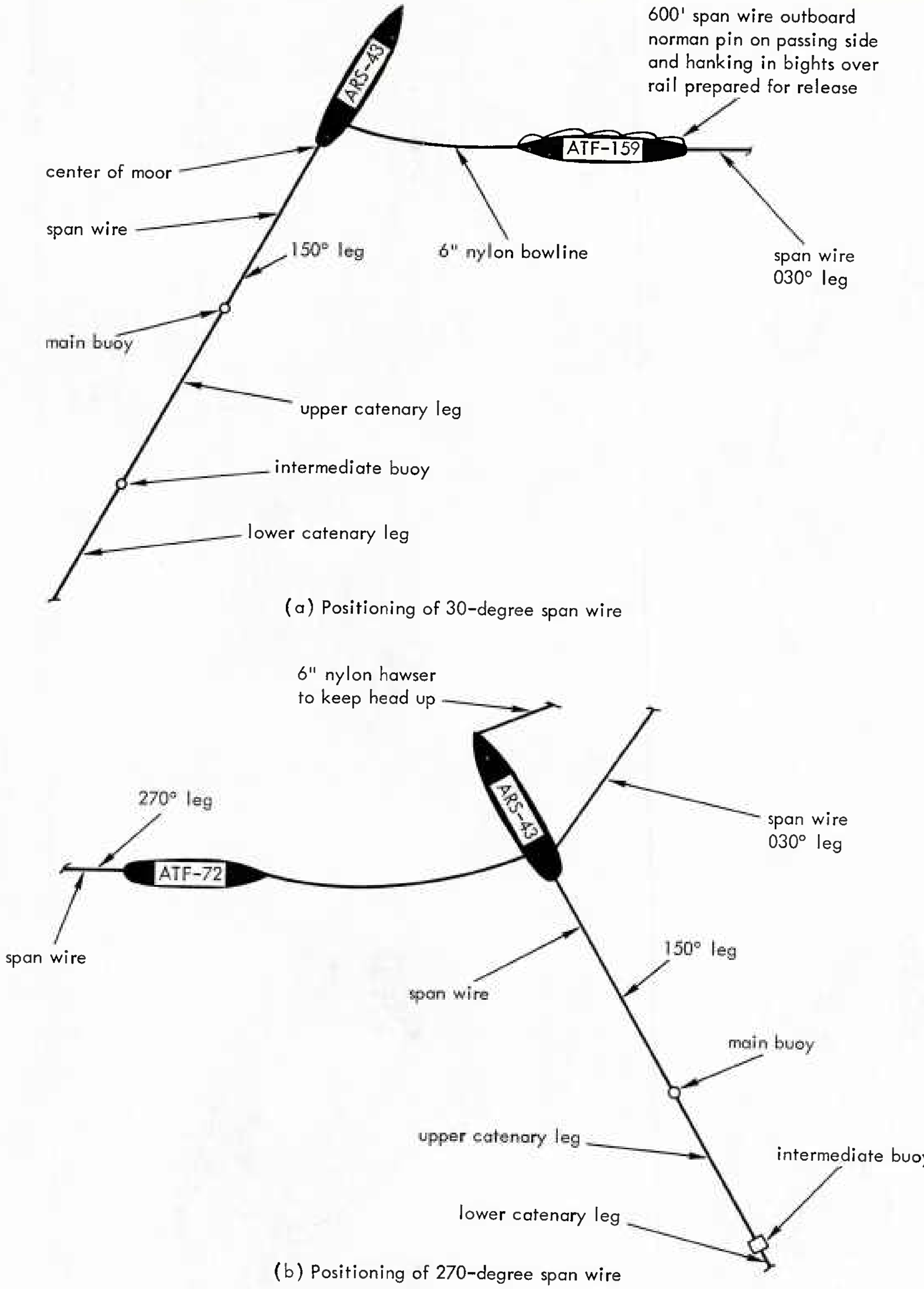
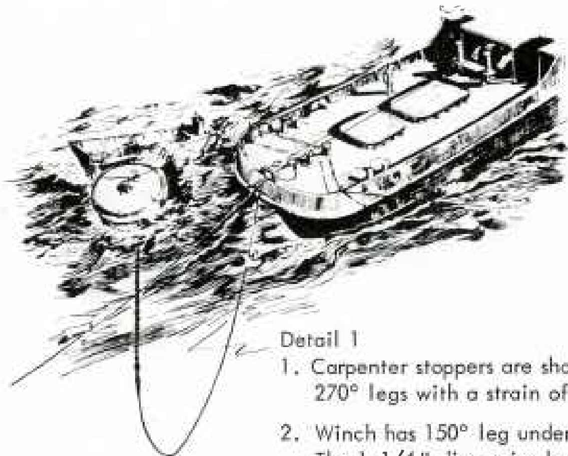
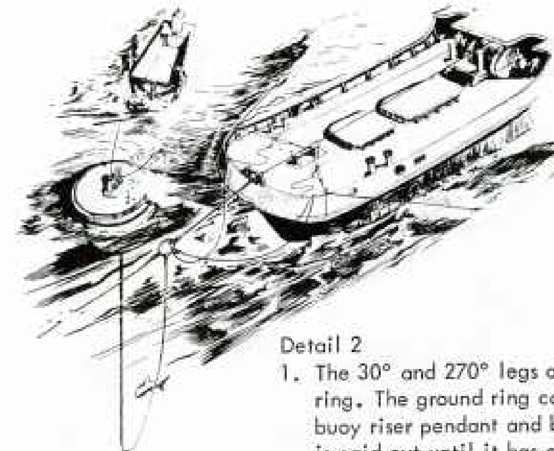


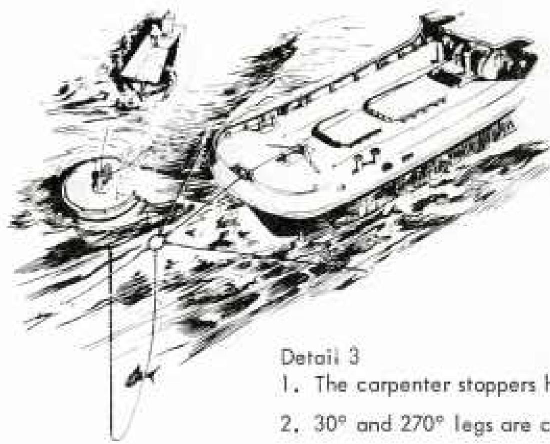
Figure F-2. Positioning of span wires.



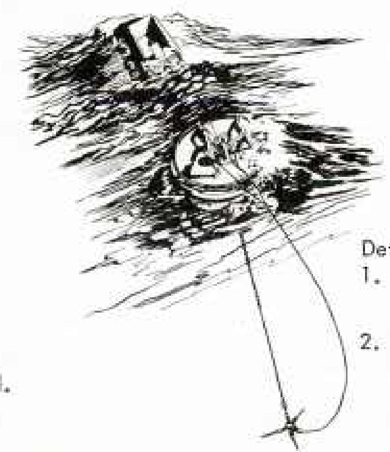
Detail 1
1. Carpenter stoppers are shown holding 30° and 270° legs with a strain of 10,000 lb.
2. Winch has 150° leg under strain of 10,000 lb. The 1-1/4" diam wire leading from the 12" ground ring to winch is the retrieving pendant.
3. The LCM is shown positioning the center buoy. The buoy riser pendant is shown connected to the ground ring.



Detail 2
1. The 30° and 270° legs are attached to ground ring. The ground ring containing the three legs, buoy riser pendant and buoy retrieving pendant is paid out until it has cleared the stern of the ARS.
2. LCM is holding the center buoy clear of the ARS.
3. A slight strain on the gypsies will cause the lanyards to release the carpenter stoppers, thus eliminating the need for personnel to be in the area as this is a very dangerous condition.



Detail 3
1. The carpenter stoppers have been released.
2. 30° and 270° legs are clear of the ARS.



Detail 4
1. Ground ring is paid out to transfer the weight from the retrieving wire to the center buoy.
2. The retrieving wire is cut to 150' length and a socket is attached. The crew of the LCM is shown attaching the retrieving wire to the center buoy which will complete the moor.

Figure F-3. Completion of TOTO II moor.

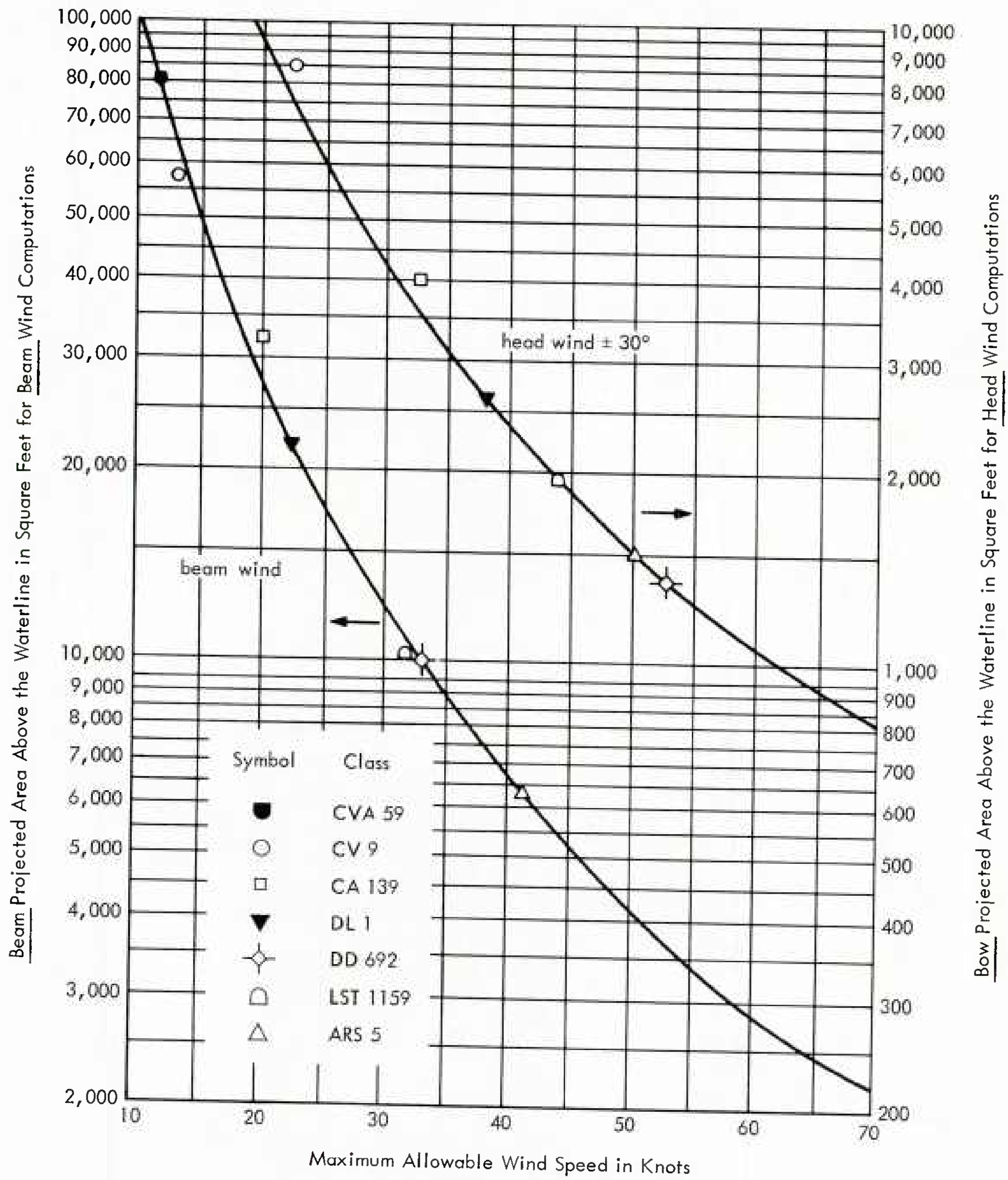


Figure F-4. Safe wind velocities for vessels tied up in TOTO II moor.

Tentative Bill of Material, TOTO II Moor

Description	Source	Quantity Required
Anchor, lightweight (LWT), 6,000 lb	M2040-378-5634	5
Shackle, chain, 2-1/2" bolt type	Crosby, Laughlin & Lebus Fort Wayne, Indiana Part No. 02150	5
Shackle, chain, 2" bolt type (heat treated)	Crosby, Laughlin & Lebus Fort Wayne, Indiana Part No. 02150	124
Shackle, chain, 1-1/4" bolt type (heat treated)	Crosby, Laughlin & Lebus Fort Wayne, Indiana Part No. G2150	6
Shackle, bending, 2-1/2" size, "F" type	Y4030-236-8391	6
Link, end, 2-1/2" size	Y4010-298-5764	6
Link, detachable, 2-1/2" size	H4010-161-9298	41
Link, detachable, pear shaped, 2-1/2" size (Baldt dwg No. L-934-18)	Baldt Anchor (Chain & Forge Division of the Boston Metals Co., P. O. Box 350, Chester, Pennsylvania	12
Chain, 2-1/2" stud link (15 ea. shots)	H4010-149-5600	25
Chain, 2-1/2" stud link, 30' long	(Cut from 15-fathom shots - refer H4010-149-5600)	9
Tool kit, detachable, link 2-1/2" size	H4010-242-8705	4
Grip cable jaw, 1-1/4" size	G5120-260-5478	14
Bridle, cable grip (for 1-1/4" stopper)	G4030-377-5675	14
Nylon rope, 6" circumference, 1,200' long	Manufacturer: Boston Naval Shipyard or Negotiated Procurement	6
Rat-tail stoppers, 16' long (for 6" circ nylon)	Manufacturer: Boston Naval Shipyard	12
Wedges (for 1-1/4" wire rope stoppers), reference BUSHIPS dwg 622699	Manufacturer: Boston Naval Shipyard	7
Ground ring 3" diameter x 12" ID	J5340-165-5557	16
Miller swivel, type 3, model HH (modified: to enlarge holes in bales from 2-5/16" diam. to 2-3/8" diam. and fitted with high-pressure seals and special bearing arrangement for 6,000-ft depth application)	Miller Swivel Products Inc. Pomona, California, or Mr. Dan Gillespie, P. O. Box 165, Dumont, N. J. Phone: Dumont 4-0148 (East Coast Representative)	41
Buoy, telephone type, 18' diam. x 9' high	C2050-L70-0170	1
Buoy, telephone type, 15' diam. x 7' 6" high	C2050-223-3658	3
Buoy, mooring, MK IV, 8' diam. x 14' 8" high	L2050-214-1732	3

Tentative Bill of Material, TOTO II Moor (Contd)

Description	Source	Quantity Required
Wire rope counter (for 1-1/2" wire rope)	Emiciclic Company, Inc. Providence, Rhode Island (list on Specifications)	4
Manila line, three strand, 5" circ	G4020-184-9805	4 coils
Manila line, three strand, 4" circ	G4020-184-9807	4 coils
Manila line, three strand, 3" circ	G4020-231-9014	10 coils
Manila line, three strand, 2" circ	G4020-231-9010	3 coils
Manila line, 21 thread, 1-1/2" circ	G4020-231-9008	3 reels
Manila line, 15 thread, 1-1/4" circ	G4020-231-9007	3 reels
Manila line, 0 thread, 1" circ	G4020-231-9005	4 reels
Acid, muriatic, (Spec O-A-86)	G6810-222-9641	36 lb
Zinc (QQ-Z-351)	G9650-240-6839	1,200 lb
Socket, wire rope, 1-1/4" size, open, fitted with hex hd bolt, nut & cotter pin, galvanized	Negotiated Procurement	38
Socket, wire rope, 1-1/4" size, closed, galvanized	Negotiated Procurement	30
Pendant, retrieving, wire rope 18" diam., 6x19 filler wire IWRC, galvanized, preformed, right regular lay 150' long, open and closed wire rope socket, allocate ends, open socket to be filled with hex head bolt, nut and cotter pin, galvanized	Negotiated Procurement	12
Pendant, suspension, wire rope, 1-5/8" diam., 6x19 filler wire, IWRC, galvanized, preformed, right regular lay, 75' long, closed wire rope socket both ends, galvanized	Negotiated Procurement	12
Wire rope, 1-1/4" diam., 6x19 filler wire, IWRC, galvanized, preformed, right regular lay, 8,000' long, open wire socket one end only, open socket to be fitted with hex bolt, and cotter pin, galvanized	Negotiated Procurement	10
Wire rope, 1-1/4" diam., 6x19 filler wire, IWRC, galvanized, preformed, right regular lay, 2,500' long, open wire rope socket one end only, wire rope socket to be fitted with hex head bolt, nut and cotter pin, galvanized	Negotiated Procurement	6
Payoff stand, wire rope	Manufacturer: Norfolk Naval Shipyard. Attention: Code 244	3
Stern roller chock assemblies for ATF 156 Class	Manufacturer & Installer: Norfolk Naval Shipyard Attention: Code 244	3
Methyl chloroform	G6810-664-0388	50 cl
Pelican hook (for 2-1/2" size chain)	Manufacturer: Boston Naval Shipyard	10

APPENDIX 7-G
SQUAW MOORING PROCEDURE

In addition to an unidentified LCM, the following vessels participated in the installation of the SQUAW mooring:

ARS-24

ATA-192

ASR-9

ATF-92

The procedure followed by these vessels is described, in outline form, in the following paragraphs excerpted from a report prepared for the Navy by Hydrospace (1964):

1. The ARS-24 dropped the anchor of the first leg; payed out anchor cable to full scope; stretched the anchor leg and set the anchor. The ARS-24 then took the support buoy from an LCM; connected the anchor leg and span wire to the ground ring; and payed out the span wire while moving toward the center of the moor. The ATA-192 then assisted the ARS-24 in holding position at the center of the array.

2. The installation of the second leg by the ASR-9 was similar, except that the bitter end of the span wire was passed to the bow of the ARS-24. The ASR-9 then cleared the area.

3. The ATF-92 dropped the anchor of the third leg; laid out the anchor cable to full scope with the assistance of the ASR-9; set the anchor and stretched the anchor cable. The ATF-92 then took the support buoy from the LCM, connected the anchor leg and span wire to the ground ring, and payed out the span wire while moving to the center of the moor. The bitter end of the span wire was then passed to the bow of the ARS-24.

4. The ARS-24 took up the span wires of the first and second legs to a tension of 20,000 pounds, and marked the position of the carpenter stoppers on the span wires.

5. The ASR-9 removed the support buoys from the first and second legs, and attached a 7-inch-circumference, 1,500-foot polypropylene line to each ground ring. The ASR-9 then passed the polypropylene lines to the bow and stern of the ARS-24.

6. The ARS-24 then took up on the first and second legs to a tension of approximately 20,000 pounds with the support buoys removed.

7. The ARS-24 cut the span wires of these legs for proper scope, as determined by on-site calculations, and installed sockets. Both 25,000-pound counterweights were then lowered to the bottom and cut to proper length.

8. The ATA-192 then towed the SQUAW hull to the center of the moor and passed it to the portside of the ARS-24.

9. The ARS-24 then transferred the first and second legs to the bow and stern of the SQUAW hull, with dynamometer links inserted. The counterweight wires, also with dynamometer links inserted, were then transferred to, and suspended from, the SQUAW hull, which remained at the surface. The ARS-24 held position at the center of the moor, using the 7-inch polypropylene lines at bow and stern. Tensions were measured in the first and second legs, and in the counterweight wires, with the polypropylene lines slack. The length of the catenary legs was then adjusted as indicated by on-site calculations.

10. The ASR-9, assisted by the LCM, attached two 17-ton buoys to the pad eyes on the top of the SQUAW hull, using wire rope pendants of proper length for the SQUAW submergence depth.

11. The ARS-24 then heaved on the third leg, to clear the SQUAW, and dropped the hull to its 200-foot depth. Tensions were measured in all of the remaining legs. The SQUAW was then raised to the surface, by pumping ballast, and the length of the catenary legs readjusted. This procedure was repeated until proper tension was recorded at the 200-foot level, at which point the SQUAW was raised and the dynamometer links were removed. The hull was then dropped to its final position in the mooring.

12. All pumping hoses were next retrieved, and the two 17-ton buoys were removed. Weights were than attached to the bitter ends of the polypropylene lines and, with these weights resting on the SQUAW deck, the lines were cast off, to be retrieved subsequently. The unused catenary leg was then retrieved by the ATF-92, and the installation was complete.

GLOSSARY

Term	Definition
Anchorage	The complete system - bottom implement, ground tackle, mooring point, and all connecting apparatus - necessary for maintaining any construction in position in the deep ocean.
Automatic tension control	In winch operations, the maintenance of reasonably uniform tension in cables by automatic controls.
Beaufort scale	A numerical scale rating winds according to ascending velocity, as follows:

Beaufort No.	State of Air	Velocity in Knots
0	Calm	0-1
1	Light airs	1-3
2	Slight breeze	4-6
3	Gentle breeze	7-10
4	Moderate breeze	11-16
5	Fresh breeze	17-21
6	Strong breeze	22-27
7	Moderate gale (high wind)	28-33
8	Fresh gale	34-40
9	Strong gale	41-47
10	Whole gale	48-55
11	Storm	56-65
12	Hurricane	Above 65

Term	Definition
Bottom detector	A device used to determine when an item being lowered is near or in contact with the ocean bottom.
Buoyancy - volume ratio and Buoyancy - weight ratio	Used in evaluating float material in sea water.
Cable bale	A package container for specially wound and secured cable for use in placement operations.
Cathodic protection	The control of corrosive electrolytic action on an underwater structure by use of an electric current in such a way that the structure is made to act as the cathode instead of the anode of an electric cell.
Consolan	A radio signal system operated by the Federal Aviation Authority primarily for aircraft service, but successfully used in at least one instance for tracking the position of deep ocean buoys.

Term	Definition
Constant-tension device	A device that will maintain a constant tension in a line by sensing and/or anticipating changes in force and automatically compensating for them. (A fully functional constant-tension device is not known to exist.)
Cost-buoyancy ratio	Expressed in dollars per pound of buoyancy and used in evaluating a buoyancy material.
Damper plate	A device, usually of perforated metal, in the shape of a plate or disk used to mitigate the oscillating or heaving motion of an object such as a buoy.
Davit	A small derrick at the side of a ship for hoisting boats, anchors, and accessories.
Deadman anchor	Any structurally sound object buried in the ground and used as an anchorage. It generally uses the passive resistance of the soil to resist displacement.
Drag force	Force on a submerged object due to its relative motion in the water.
Drag coefficient	Nondimensional constant used to estimate the drag force on moorings and elements of moorings. It depends upon the shape and roughness of the object and on the Reynolds number associated with the flow.
Drag-type anchor	An anchor that develops its holding power through embedment by dragging on the bottom a specified distance according to the anchor size and type of bottom soil.
Drilled-in anchor	A pile or piling placed into the bottom by drilling. After placement, grouting is usually employed to better fuse the pile to the surrounding material.
Drogue	A device shaped like a funnel or cone with a wide mouth which is attached to a line or long rope to act as a dragging force for slowing descent or other movement in the water; usually fabricated of canvas or other cloth.
Dynamic anchoring or dynamic positioning	Maintaining a floating structure on station and orienting it by means of propulsive forces that counteract wind, wave, current, or other influences.
Excursion	Displacement of an anchored structure from a datum reference point. The term is generally used in reference to a vertical or horizontal plane.
FLIP	Floating Instrument Platform, a large manned buoy constructed for oceanographic research.
FORDS	Floating Oceanographic Research and Development Station, a large, stable, free-floating structure under consideration for deep-sea operations, such as lowering and lifting great loads.
Fouling	Generic term for the mass of organisms, animal and vegetable, which becomes attached to the underwater surface of a construction.

Term	Definition
Grappel (grapnel)	An instrument with several iron or steel claws used in dragging or grappling operations, usually in areas where bottom visibility is zero.
Grappling	Act of trying to hook or grasp an object by means of dragging a grapple along the sea bottom.
Ground tackle	The anchors, cables, and other equipment used for securing a vessel at anchor.
Hand layup process	A process of applying fiber glass in woven rovings by first painting the surface with resin-catalyst bonding and then laying on a sheet of fiber glass.
Machine sprayup process	A process of applying fiber-glass coating to a form using a double-barreled pressure gun, projecting particles of fiber glass from one barrel, and simultaneously projecting a resin-catalyst bonding agent from the other barrel.
Mooring point or moor point	That location on an anchorage system to which the structure being anchored is attached.
NOMAD	Navy Oceanographic and Meteorological Automatic Device, a heavily instrumented oceanographic buoy anchored in the Gulf of Mexico.
Notch sensitivity	Fatigue. Notch sensitivity can be evaluated as the ratio of the endurance limit of a standardized notched specimen to that of a smooth specimen.
Pendant (also pennant, painter)	A line or rope, not a part of the primary connecting apparatus of an anchorage system, used to connect primary parts or restrain appurtenant objects of the mooring.
Pinger	An automatic transmitter of preset sound signal patterns used to help locate submerged buoys or other objects.
Propellant embedment anchor (also explosive anchor)	A type of anchor, largely in the development state, that is embedded into the bottom by an explosive propellant charge.
Reynolds number	An index of the form of flow; a nondimensional term used in evaluating the flow of a fluid about the perimeter of an immersed object or within a channel or pipe.
Riser line	A line between two major components of a mooring that are at different levels. The riser line may or may not be a main holding line to which the structure being anchored is secured.
Separation device	A contrivance placed at a strategic place in the connecting apparatus that will permit separation of the system at that point on overload or when otherwise desired.
Shock mitigator	Any device used in anchorage systems to absorb and lessen the shock imposed on vital components by motion of the anchored structure, whatever the cause.

Term	Definition
Shot of chain	Nominally, a chain section 90 feet in length.
SNAP	Systems for Nuclear Auxiliary Power; being studied and developed for a variety of space and terrestrial uses.
SPAR	Seagoing Platform for Acoustic Research, a large unmanned instrumented buoy that has been constructed and placed in service for research purposes.
STOP	Stable Ocean Platform, a large manned buoy proposed for construction and to be used primarily as a sea station for satellites.
STU	Submersible Test Unit. A series of these units, each containing thousands of samples, are being placed in deep water by the U. S. Naval Civil Engineering Laboratory in a continuing study of the influence of the deep ocean environment on materials.
Surge	The rise and fall of a structure (ship) at anchor; also, the undulating movement of waves.
Swing	The movement of an anchored structure about its mooring point.
Syntactic foam	Commercially available foam consisting of closed-cell-type microscopic hollow spheres of phenolic resin held together by a binder.
Telemeter	An electrical instrument for measuring a quantity, transmitting the result to a distant station, and there indicating or recording the quantity measured.
Thermistor	Acronym formed from thermal and resistor. A resistor whose value varies with temperature in a definite desired manner.
Thermocline	Temperature gradient; also used to designate an anomalous section of the temperature gradient. The maximum gradient usually occurs between 100 and 200 meters in depth.
Tiltmeter	A device used in conjunction with a taut line connected to the bottom to sense the horizontal excursion of a surface vessel from a reference datum point by the measure of tilt in the taut line.
Toroid	A surface generated by the rotation of a plane closed curve about an axis lying in its plane (in this work, a circular type of construction with a hole in the center, like a doughnut).
TOTO	Tongue Of The Ocean, a geographic location near the Bahama Islands.
Transponder	A transmitter-receiver facility whose function is to transmit signals automatically when the proper interrogation is received.
Weak link	A type of separation device incorporated into a system to cause failure on overload at a strategic point in order to minimize the amount and seriousness of loss.

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